CHAPTER 12

EROSION AND SEDIMENT POLLUTION CONTROL

12.0 INTRODUCTION

Controlling erosion and sedimentation (E&S) during construction of our highways is an integral part of protecting and maintaining our water resources. For this reason, the Federal Clean Water Act, 33 U.S.C. § 1251 et seq., and the Pennsylvania Clean Streams Law, Act of June 22, 1937 (P.L. 1987, No. 394) as amended 35 P.S. § 691.1 et seq. provide regulatory requirements for construction activities and the management of stormwater runoff generated by highways. Best Management Practices (BMPs) serve as the primary means of meeting these requirements. BMPs include activities, facilities, measures, or procedures used to prevent or reduce the discharge of pollutants to waters and to minimize erosion and sedimentation. This Chapter categorizes Erosion and Sediment Pollution Control (E&SPC) into three groups: Stabilization BMPs, General BMPs, and In-Channel BMPs. These BMPs are temporary controls used by construction site operators during the period of earth disturbance to control erosion and sedimentation during construction activities.

This chapter will also: 1) give an overview of the regulatory basis for these requirements; 2) guide the reader through the steps of coordinating with the federal, state, and local regulatory authorities; 3) explain the types of analyses that should be performed; 4) describe a variety of BMPs including where and when they can/should be used and how they should be designed to achieve their optimal functionality.

This guidance is consistent with the following regulations:

- Pennsylvania's Clean Stream Law, Act of June 22, 1937 (P.L. 1987, No. 394) as amended 35 P.S. § 691.1 et seq.
- The Federal Clean Water Act, 33 U.S.C. § 1251 et seq.
- 40 CFR § 122.26 – Implementation of the National Pollutant Discharge Elimination System (NPDES) Program – Stormwater Discharges (USEPA, 2006).
- Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 102: Erosion and Sediment Control.
- Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 92: NPDES Permitting, Monitoring, and Compliance.
- Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 93: Water Quality Standards.

The Pennsylvania Department of Environmental Protection (PA DEP) and the Pennsylvania County Conservation Districts (CCDs) participated in the development of this chapter.

It should be noted that all dimensions shown in figures are in millimeters unless otherwise noted. U.S. Customary units are provided in parentheses.

12.1 REGULATORY REQUIREMENTS

A. Overview of the Regulations. Two primary laws address the regulation and management of the discharge of stormwater from construction sites (during construction and post construction): the Federal Clean Water Act, 33 U.S.C. § 125.1 et seq., and the Pennsylvania Clean Streams Law, Act of June 22, 1937 (P.L. 1987, No. 394) as amended 35 P.S. § 691.1 et seq. The Federal NPDES regulations (40 CFR Part 122); PA Code, Title 25, Chapter 92 regulations; and PA Code, Title 25, Chapter 102 regulations have been promulgated pursuant to these two laws, and it is these regulations that set forth the criteria for the permitting of construction projects that involve the discharge of stormwater from construction sites.

While this chapter focuses on the NPDES, Chapter 92, and Chapter 102 regulations, the requirements they impose on a designer, and the associated permit programs, there are numerous other related laws which have been promulgated pursuant to the Clean Water Act and the Clean Streams Law that become intertwined with these permits during the design process and therefore need to be summarized. Appendix 12A, *E&S Related Regulations*, Section 12A.1 provides an overview of related regulations that have an E&SPC and/or Post-Construction

Stormwater Management (PCSM) component, and/or may regulate activities that require submission of an E&SPC and/or PCSM Plan.

1. The Federal National Pollutant Discharge Elimination System (NPDES). The NPDES was authorized by the Federal Clean Water Act, and is intended to control water pollution by regulating stormwater discharges into waters of the United States. While this is a Federal program, it is administered by PA DEP.

40 CFR Part 122 contains provisions to implement the NPDES Program under the Clean Water Act. These regulations serve as the guidelines for what each state must do to develop its own NPDES Program, in lieu of a Federal program. Related permits include, but are not limited to the following:

- NPDES Permit for Industrial Wastewater (Part 1).
- NPDES Permit for Stormwater Discharges Associated with Industrial Activities.
- NPDES Permit for Stormwater Discharges Associated With Construction Activities.
- NPDES Phase II Municipal Separate Storm Sewer System (MS4) Permit.

There are two types of NPDES permits for construction activities: a general permit and an individual permit. PA DEP has designed a single set of forms that serve as either the Notice of Intent (NOI) for the General NPDES Permit, or as the application for the Individual NPDES Permit. Information regarding specific requirements of the General and Individual Permits, as well as the qualification for the General Permit can be found on PA DEP's website, at www.dep.state.pa.us. A summary of the qualifications for the General NPDES Permit can be found in Section 12.1.B.

A NPDES Permit is required for projects that propose earth disturbances (other than agricultural plowing and tilling, and timber harvesting activities) that:

- Disturb from 0.4 hectare (1 acre) to less than 2 hectares (5 acres) with a point source discharge to surface waters of the Commonwealth (Note: Based on State regulations, PA DEP permitting requirements apply to surface waters of the Commonwealth, which is broader coverage than the Federal requirement which extends only to waters of the U.S.); or
- Disturb five or more acres (regardless of the type of discharge).

Another program under NPDES is the Phase II MS4 Program. The use of construction and post construction BMPs and an E&SPC Plan serve to meet certain regulatory requirements within the Phase II NPDES Permit. Additional information regarding the NPDES Phase II MS4 program and permit is provided in Appendix 12A, *E&S Related Regulations*, Section 12A.1.

As stated in the General or Individual NPDES permit instructions, a point source is defined as any discernible, confined and discrete conveyance, including, but not limited to, any pipe, ditch, channel, tunnel, well, discrete fissure, or container from which pollutants are or may be discharged.

2. PA Code, Title 25, Chapter 92: NPDES Permitting, Monitoring and Compliance. Chapter 92 was promulgated pursuant to the Pennsylvania Clean Streams Law, provides state implementation authority for the NPDES Program. The NPDES Permits are governed under Chapter 92 and are administered by PA DEP. The Permits governed under Chapter 92 are the same as those listed in Section 12.1.A.1.

3. Commonwealth of Pennsylvania, PA Code, Title 25, Chapter 102: Erosion and Sediment Control. Chapter 102 provides regulatory guidance in accordance with Sections 5 and 402 of the Clean Streams Law, and the NPDES Permits for Stormwater Discharges Associated with Construction Activities. The primary pollutant of concern under Chapter 102 is sediment. Chapter 102 imposes requirements on earth disturbance activities that create accelerated erosion or a danger thereof, and which require planning and implementation of effective soil conservation measures (Section 102.2). It requires individuals to develop, implement, and maintain an approved E&SPC Plan prior to performing earth disturbance activities. In order to meet the requirements, the E&SPC Plan must include the implementation of BMPs to minimize erosion and discharge of sediment. In addition, any timber harvesting or roadway maintenance activity disturbing 25 or more acres of land must apply for, and receive an E&SPC Permit according to Chapter 102 regulations (roadway maintenance activities that disturb less than 25 acres are exempt from permitting requirements). Permitting for

PA Code, Title 25, Chapter 102 is handled by the NPDES Permit for Stormwater Discharges Associated with Construction Activities.

B. Permitting Process - The NPDES Permit Application For Stormwater Discharges Associated With Construction Activities. A General Permit (sometimes referred to as a PAG-2 Permit) can be used unless one or more of the following conditions occur. Specifics on these conditions can be found in the PA DEP Instructions for a General or Individual NPDES Permit for Stormwater Discharges Associated with Construction Activities, which can be found on PA DEP's website at www.dep.state.pa.us. These conditions include, but are not limited to the following:

- The project discharges to waters with a designated or existing use of High Quality (HQ) or Exceptional Value (EV) pursuant to PA Code, Title 25, Chapter 93.
- The project discharges to EV wetlands.
- The project is capable of affecting existing water quality standards.
- The project may affect threatened or endangered species or their critical habitat.
- Discharges would contain hazardous pollutants, toxics, or other substances that may cause or contribute to an increase in mortality or morbidity in an individual or the total population, or would pose a substantial present or future hazard to human health or the environment when discharged into waters of the Commonwealth.
- Discharges which individually or cumulatively have the potential to cause significant adverse environmental impact.
- Discharges to waters for which general permit coverage is prohibited under PA Code, Title 25, Chapter 92.83.

Where these instances occur, an Individual NPDES Permit is required. An E&SPC Plan is required as part of both the General and Individual NPDES Permits (as described under Chapter 102 above), along with a Preparedness, Prevention, and Contingency (PPC) Plan and a PCSM Plan. For guidance on how to prepare these plans, refer to Chapter 4, *Documentation and Document Retention*, Section 4.1.B for the NPDES permit application, Section 4.1.C for E&SPC Plans, Section 4.1.F for PPC plans and Section 4.1.E for PCSM plans. The PCSM Plan identifies BMPs that manage and treat stormwater discharges after construction resulting from additional impervious surfaces. The purpose of the PCSM BMPs is to prevent or minimize any increase in quantity (rate and volume) of runoff while also minimizing the factors affecting the quality. In areas where approved Act 167 Stormwater Management Plans exist, the PCSM Plans should be consistent with standards of the Act 167 Plan. (Act 167 Plans are stormwater management plans adopted by a county and approved by PA DEP in accordance with Sections 5 and 9 of the Pennsylvania Storm Water Management Act, of October 4, 1978, P.L. 864 No. 167 32 P.S. § 680.1 et seq. (as amended by Act 63) as described in Appendix 12A, *E&S Related Regulations*, Section 12A.1). See Chapter 14, *Post-Construction Stormwater Management,* for more details on PCSM BMPs.

As discussed above, the NPDES, Chapter 92, and Chapter 102 regulations require permit application and approval for different earth disturbance activities. Table 12.1 provides an overview of these activities and their associated permits.

It is important to determine what regulations and permits apply to project activities early in the project development process. By doing so, coordination with the appropriate resource agencies, county and local planning offices, CCDs, and others can be conducted to gain consensus on approaches and best management practices to best avoid and/or minimize impacts to streams and other natural resources due to erosion and sedimentation or stormwater runoff. This section serves as a summary of the laws and regulations governing earth disturbance activities. Additional details regarding each in the regulation and its associated permits and requirements can be obtained using the citations and website links provided in the preceding sections.

Table 12.1 Relationship of Earth Disturbance Activities, Regulations, and Associated Permits

Activity	Regulations	Requirements/Permits
Earth disturbance of any amount within a special protection watershed	PA Code, Title 25, Chapter 102: Erosion and Sediment Control PA Code, Title 25, Section 93.4c: Implementation of Antidegradation Requirements (if point source discharge).	Written E&SPC Plan
Earth disturbance from 5,000 square feet to less than 1 acre	PA Code, Title 25, Chapter 102: Erosion and Sediment Control	Written E&SPC Plan
Earth disturbance of 1 to less than 5 acres with no point source stormwater discharge	PA Code, Title 25, Chapter 102: Erosion Control	Written E&SPC Plan
Earth disturbance of 1 to less than 5 acres with a point source stormwater discharge to surface waters of the Commonwealth*	PA Code, Title 25, Chapter 102: Erosion and Sediment Control PA Code, Title 25, Chapter 92: NPDES Permitting, Monitoring, and Compliance PA Clean Streams Law Federal Clean Water Act, Section 402 Federal NPDES Regulations at 40 CFR Part 122 PA Stormwater Management Act PA Code, Title 25, Chapter 93: Antidegradation regulations apply to all waters not just special protection waters.	Written and Approved E&SPC Plan NPDES Permit for Stormwater Discharges Associated With Construction Activities. Note: both a General Permit (PAG-2) and an Individual Permit are available. See the summary above on NPDES for details on the qualifications for the General Permit.
All earth disturbances of 5 or more acres *	PA Code, Title 25, Chapter 102: Erosion Control PA Code, Title 25, Chapter 92: NPDES Permitting, Monitoring, and Compliance PA Clean Streams Law Federal Clean Water Act, Section 402 Federal NPDES Regulations at 40 CFR Part 122 PA Stormwater Management Act PA Code, Title 25, Chapter 93: Antidegradation regulations apply to all waters not just special protection waters	Written and Approved E&SPC Plan NPDES Permit for Stormwater Discharges Associated With Construction Activities. Note: both a General Permit (PAG-2) and an Individual Permit are available. See the summary above on NPDES for details on the qualifications for the General Permit.

* Activities that occur within EV or HQ Watersheds, as per PA Code, Title 25, Chapter 93, require an Individual NPDES Permit for Stormwater Discharges Associated With Construction Activities.

12.2 OVERALL PROJECT COORDINATION

Planning for E&SPC BMPs and PCSM BMPs, when required, should be initiated as early in the design process as possible. Integral to this planning is the initiation of a proactive coordination effort with the agencies involved in reviewing and approving plans and permits related to E&SPC and PCSM efforts/controls. The magnitude and complexity of a project will dictate the approvals required and the type and amount of coordination necessary. The approach for a project needs to be tailored to fit that specific project. This section provides a framework to lead the designer through the process of developing a planned and coordinated approach, and identifies key issues to be considered during project development.

A. Early Planning. Early planning is a key element to the successful development and approval of an E&SPC Plan. By planning early, the designer can accelerate project delivery, reduce construction change orders, and reduce overall project costs. This is accomplished by identifying critical design issues early, so that design solutions can be considered at the earliest point possible. These solutions can be incorporated into the initial project design, rather than having to perform design modifications later in the design process to address E&SPC and PCSM issues.

Another important aspect of the planning process is to identify any specific administrative requirements of the CCDs. Although similar, there are differences in the county requirements, including but not limited to, plan presentation and content, the number of draft and final E&SPC Plans needed, whether review fees are required and their amounts, and whether the CCDs have their own E&SPC application forms. It should be noted that review fees are waived for state agencies. By knowing the requirements of the CCD ahead of time, the proper information can be collected and assembled, and the proper contacts can be made early on to help expedite the process.

B. Agency Coordination. Agency coordination can be important to the time-efficient preparation and approval of E&SPC Plans. There are two primary agencies involved in the E&SPC and PCSM process: PA DEP and the CCDs.

1. Pennsylvania Department of Environmental Protection. PA DEP has oversight into the review and approval of E&SPC Plans as required by Title 25, Chapter 102, and review and approval authority for permits under the NPDES Program and Title 25, Chapter 92. Although PA DEP often delegates their approval authority for E&SPC Plans and NPDES Permits to the CCDs, they are still the primary regulatory authority. Coordination with PA DEP is therefore essential in the process of obtaining permits. They can provide useful input into implementation of E&SPC and PCSM Plans. PA DEP should be given the opportunity to be involved in agency field views and agency coordination meetings for the project. This will help to ensure that they have adequate information about the project, and have an opportunity to help identify project concerns, and offer potential solutions early in the design process.

2. County Conservation Districts (CCDs). In many counties, PA DEP has delegated review and approval authority for E&SPC Plans to the CCD. Some CCDs also have authority for the review and approval of NPDES Permits. This is based on their Delegation Level. Coordination with the CCDs is important for the timely approval of E&SPC and Stormwater Management Plans.

Starting coordination early in the project development process ensures that development of a strategy for control of erosion, sediment, and stormwater occurs at the most appropriate stages of project development. Table 12.2 provides a template for coordination between PennDOT and the CCDs. Columns 2 through 4 of Table 12.2 separate projects by size and complexity using the level of the National Environmental Policy Act (NEPA) documentation and the project type as indicators. The left column (Column 1) lists some of the major project activities in the project development process. The suggested level and frequency of coordination is related to the magnitude and complexity of the project.

Table 12.2 Suggested Points for Project Coordination with County Conservation Districts

	Environmental Documentation Level	**CEE[1]**	**EA[1]**	**EIS[1]**
	Typical Project Type(s)[2]	**NA, BR, 3R/4R Betterment**	**NA, BR**	**NA**
Project Activities	Scoping Field View	—	—	—
	Initial Agency Coordination	X[4]	X	X
	ACM Coordination/Agency Field Views[3]	—	X	X
	Public Meetings	—	—	X
	Draft NEPA Document	—	—	X
	Final NEPA Document	—	X	X
	Design Field View	X[4]	X	X
	Pre-Application Meeting	X[4]	X[4]	X
	Pre-Construction Meeting	X[4]	X[4]	X

[1] An "X" indicates a suggested coordination point with the CCD.
[2] Project types listed are intended to reflect the general magnitude of the projects.
[3] CCDs should be invited to attend ACM-type meetings and field views – if a meeting or field view is being held with one specific agency or to address one specific issue, it may not be necessary to invite the Conservation District.
[4] Coordination later in project development may not be necessary for certain types of projects.

KEY:
CEE = Categorical Exclusion Evaluation
EA = Environmental Assessment
EIS = Environmental Impact Statement
NEPA = National Environmental Policy Act
ACM = Agency Coordination Meeting
NA = New Alignment
BR = Bridge Replacement
3R/4R = Resurfacing, Restoration, Rehabilitation, & Reconstruction
Betterment = Betterment Projects

Holding joint meetings between PA DEP and the CCDs can be very helpful in accelerating a project by ensuring that communication among the agencies involved occurs "early and often", thereby fostering a coordinated effort to find solutions and make decisions regarding unique situations or areas of concern. Appendix 12D, *E&S Initiative Coordination Information***,** provides the correlation between the various PennDOT Districts, the PA DEP Regional Offices, and the CCDs; it also provides a quick reference of the contact information for the CCD staff and PA DEP Regional Offices.

C. PennDOT District E&S Coordinator Role. The PennDOT District E&S Coordinator serves as the primary point of contact for E&SPC issues, activities, and permits. By providing this point of contact for PA DEP, the CCDs, the Inspector-in-Charge, and others, consistency is provided for all groups involved when dealing with E&SPC concerns. This ensures that concerns will be handled in a timely and efficient manner.

In addition to serving as a primary point of contact, the E&S Coordinator is responsible for coordination of PennDOT's representation at the PA DEP Regional Round Table Meetings. This involves suggesting a PennDOT representative to attend the Round Table Meetings, being responsible for gathering information from the design, construction, and maintenance units, and supplying that information to the selected meeting attendee prior to the meeting, as appropriate.

The role of the E&S Coordinator is very important to maintaining an efficient E&SPC process. By attending the Round Table Meetings, the E&S Coordinator helps to maintain an effective working relationship with PA DEP and the CCDs, and helps to keep PennDOT up to date on new initiatives and concerns regarding E&SPC issues. In addition, by providing a single point of contact, the E&S Coordinator assists the resource agencies, local officials, and others in providing valuable comments and insight earlier in the process, and provides a conduit for two-way communication and discussions, resulting in an overall project that is more sensitive to water quality issues.

12.3 DESIGN

A. Introduction. Regulatory approval of E&SPC and PCSM Plans can have a significant influence on the design process and the date construction starts. It is important to begin E&SPC and PCSM design early, follow the procedures set forth herein, and keep communication open between the E&SPC and PCSM designers, regulatory agencies (refer to Section 12.2), and other members of the project team. Communication with PennDOT maintenance personnel may also benefit the design process; drawing upon experience and past projects can shed light on those E&SPC and PCSM measures that work best in certain areas.

The purpose of E&SPC Plans is to provide methods for controlling erosion and sediment during the construction of a project. The purpose of PCSM Plans is to provide methods for controlling post-construction stormwater runoff so it will not degrade the physical, biological, and chemical qualities of the receiving surface waters. E&SPC and PCSM should be considered in the preliminary design phase. Guidelines for the presentation of E&SPC Plans are found in Publication 14M, Design Manual, Part 3, *Plans Presentation*.

The following sections provide a framework for gathering information and applying it to E&SPC designs. Since any right-of-way needs must be included in the final Right-of-Way Plan, it is important to evaluate the need for and location of E&SPCs in the preliminary engineering phase in order to provide accurate and complete information for final design.

Publications from the Federal Highway Administration (FHWA) and PA DEP provide commonly recognized methods to design erosion protection and are referenced throughout this guide. The FHWA's publications for hydraulic engineering, including Hydraulic Engineering Circulars (HEC), are available through its website (www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm). The information is subject to frequent changes resulting from updated research findings and design practices. These publications include:

1. FHWA.

a. HEC-11, *Design of Riprap Revetment*. Provides procedures for the design of riprap revetments to be used as channel bank protection and channel linings on larger streams and rivers (i.e., having design discharges generally greater than 1.4 m^3/s (50 cfs)). (FHWA, 1989)

b. HEC-14, *Hydraulic Design of Energy Dissipators for Culverts & Channels*. Provides design information for analyzing energy dissipation problems at culvert outlets and in open channels. (FHWA, 2006)

c. HEC-15, *Design of Roadside Channels with Flexible Linings*. Provides guidance for the design of stable conveyance channels using flexible linings. The procedures of HEC-15 are applicable for channels carrying discharges less than 1.4 m^3/s (50 cfs). (FHWA, 2005a)

d. HEC-22, *Urban Drainage Design Manual*. Provides guidance for the design of storm drainage systems which collect, convey, and discharge stormwater flowing within and along the highway right-of-way. (FHWA, 2001b)

e. HEC-23, *Bridge Scour and Stream Instability Countermeasures*. Provides guidance for designs implemented by various state departments of transportation in the United States. (FHWA, 2001c)

2. PA DEP.

a. *Erosion and Sediment Pollution Control Program Manual*. Provides an overview and specific design criteria for a vast variety of E&SPC BMPs. (PA DEP, 2000)

b. *Pennsylvania Stormwater Best Management Practices Manual.* Provides an overview and specific design criteria for PCSM BMPs. (PA DEP, 2006)

c. *Water Quality Antidegradation Implementation Guidance*. Provides overview of antidegradation regulations and guidance, including specific requirements for HQ and EV waters. (PA DEP, 2003)

B. Factors Influencing Erosion

1. Principal Factors. The inherent erosion potential of any area is determined by four principal factors: soil characteristics, vegetative cover, topography and climate. Although each is discussed separately herein, they are interrelated in determining erosion potential.

2. Soil Characteristics. The properties of soil that influence erosion by rainfall and runoff are those that affect the infiltration capacity of a soil and those that affect the resistance of a soil to detachment and being carried away by falling or flowing water. Soils containing high percentages of fine sands and silt are normally the most erodible. As the clay and organic matter content of soils increases, the erodibility decreases. Clays act as a binder to soil particles, thus reducing erodibility. However, although clays have a tendency to resist erosion, once eroded they are easily transported by water. Soils high in organic matter have a more stable structure that improves their permeability. Such soils resist raindrop detachment and infiltrate more rainwater. However, soils with high organic content are less desirable for structural fill due to issues related to decomposition. Clean, well-drained and well-graded gravels and gravel-sand mixtures are usually the least erodible soils. Soils with high infiltration rates and permeabilities reduce the amount of runoff and, as a result, the erosion potential.

3. Vegetative Cover. Vegetative cover plays an important role in controlling erosion in the following ways:

- Shields the soil surface from the impact of falling rain.
- Holds soil particles in place.
- Maintains the soil's capacity to absorb water.
- Slows the velocity of runoff.
- Removes subsurface water improving infiltration and permeability, between rainfalls through the process of evapotranspiration.

By limiting and staging the removal of existing vegetation and by decreasing the area and duration of exposure, soil erosion and sedimentation can be significantly reduced. Special consideration should be given to the maintenance of existing vegetative cover on areas of high-erosion potential such as erodible soils, steep slopes, drainage ways and the banks of streams.

4. Topography. The size, shape and slope characteristics of a watershed influence the amount and rate of runoff. As both slope length and gradient increase, the rate of runoff increases, and the potential for erosion is magnified. Slope orientation can also be a factor in determining erosion potential.

5. Climate. The frequency, intensity and duration of rainfall are fundamental factors in determining the amounts of runoff produced in a given area. As both the volume and velocity of runoff increase, the capacity of runoff to detach and transport soil particles also increases. Where storms are frequent, intense, or of long duration, erosion risks are high. Seasonal changes in temperature and variations in rainfall, help to define the high erosion risk period of the year. When precipitation falls as snow, no erosion will take place. However, in the spring the melting snow adds to the runoff and erosion hazards are high. Because the ground is still partially frozen, its absorptive capacity is reduced. Frozen soils are relatively erosion-resistant. However, soils with high moisture content are subject to uplift by freezing action and are usually very easily eroded upon thawing.

C. Erosion and Sediment Pollution Control (E&SPC) Plan. E&SPC Plan development begins in the Preliminary Engineering Phase of a project. E&SPC BMPs can be classified as either temporary or permanent, depending on whether they will remain in use after construction is complete.

The designer should approach the E&SPC design by evaluating the E&SPC principles listed below. These principles usually are integrated into a system of vegetative measures, structural measures, and management techniques to develop a plan to prevent erosion and control sediment. In most cases, a combination of limiting time of exposure, judicious selection of erosion control practices, and use of sediment trapping facilities will be the most practical strategy.

E&SPC Principles

1. Plan the highway project to fit the particular topography, soil types, drainage patterns and natural vegetation in the most practical way. Try to avoid locations with steep slopes and erodible soils where possible.

2. Plan the phases or stages of construction to minimize the extent and duration of soil exposure. Disturbed areas, not currently under construction, should have temporary or permanent stabilization. Grading should be completed as soon as possible after its initiation. As soon as the grade is finalized, permanent surface stabilization cover should be established in the area. As cut slopes are made and as fill slopes are brought up to grade, these slopes should be stabilized as the work progresses.

3. Apply erosion control BMPs onsite to prevent accelerated erosion. Keep soil covered as much as possible with temporary or permanent vegetation or with various mulch materials. Special grading methods, such as roughening a slope along the contours or tracking with a cleated dozer, may be used. Other practices include diversion structures to divert surface runoff from exposed soils, and grade stabilization structures, such as Geocell Slope Confinement System, Polyacrylamides, and Articulated Concrete Block Revetment System, to prevent erosion caused by surface runoff.

4. Apply perimeter control practices to protect the construction site from upslope off-site runoff and to prevent sedimentation damage to areas downslope of the construction site. This principle relates to using effective means to prevent sediment-laden runoff from exiting the site without first being treated by an E&SPC BMP. BMPs are practices that effectively isolate the construction site from surrounding properties and prevent sediment that is produced from being transported off of the site. Diversions, berms, sediment traps, silt barrier fences, vegetative and structural sediment control measures are used as perimeter controls. Generally, sediment can be retained by two methods: (a) filtering runoff as it flows through an area, and (b) impounding the sediment-laden runoff for a period of time so that the soil particles settle out.

5. Keep runoff velocities low and retain sediment on the site as much as possible. Removal of existing ground cover and loss of permeable surface area during construction may increase both the volume and velocity of runoff. These changes must be considered when designing erosion controls. Keeping slope lengths short, gradients low, and preserving natural vegetative cover can keep stormwater velocities low and limit erosion hazards. Runoff from the construction site should be treated by appropriate sediment removal BMPs and then conveyed to a stable outlet using storm drains, diversions, stable waterways or similar measures.

6. Use appropriate methods to manage groundwater and stream base flows from work area. In-channel work may require regulatory permits and implementation of BMPs for diverting stream base flows around the work area. Effective diversion moves the stream base flows around the work area and introduces it back into the natural drainage course, minimizing the impact to the stream environment. If the diversion involves a channel, appropriate lining will prevent additional sediment from polluting the stream. In-channel work may require dewatering in combination with a diversion.

7. Construction Scheduling (Staging of Earthmoving Activities). Work should be planned to limit the time soils are exposed. E&SPC facilities should be made operational prior to each earth disturbance and prior to use. NOTE: It may be helpful to coordinate this aspect of E&SPC Plans with the MPT plan.

D. Post-Construction Stormwater Management (PCSM) Plan. A PCSM Plan includes a written narrative, identification and location of permanent BMPs, plan drawings of permanent BMPs, operation and maintenance procedures and supporting calculations and measurements. Refer to Chapter 14, *Post Construction Stormwater Management* for information on PCSM design and policy. PCSM discharge data and supporting calculations are required on the Notice of Intent (NOI) form for the general and individual NPDES permits.

E. Ongoing Coordination. In addition to the coordination discussed in Section 12.2 it is important to coordinate the E&SPC design with other areas of the overall project to avoid conflicts and incorporate additional design considerations.

The designer needs to ensure that BMPs will be placed to avoid potential disturbance to their integrity or function. It is also important to place BMPs as to avoid potential construction and traffic disturbances. The following areas should be considered:

1. Clear Zone. The designer should consider Clear Zone issues when designing and placing E&SPC and PCSM BMPs. Refer to Publication 13M, Design Manual, Part 2, *Highway Design*, Chapter 12.

2. Maintenance and Protection of Traffic (MPT). The designer should coordinate E&SPCs with the MPT Plan to ensure that good traffic patterns are maintained during construction and that effective E&SPC BMPs are implemented at the same time. BMPs that are incompatible with traffic should not be placed in areas where traffic will traverse them.

3. Construction Phasing/Sequencing. The designer should be aware of the planned project phasing to provide adequate protection of BMPs during the project construction cycle and to ensure that E&SPC BMPs have an adequate useful life. For example, when placing a Sediment Basin consider if a Sediment Basin is needed for just one phase or multiple phases of construction. If one is needed for multiple phases, the designer should attempt to place it in a location where it can be used for the multiple phases.

4. Right-of-Way. The appropriate selection of effective BMPs will require earlier effective right-of-way impact planning. Inappropriate selection of ineffective BMPs is not an acceptable alternative to early effective right-of-way impact planning. Where practical, E&SPC devices should be located within the normal right of way. After the E&SPC and PCSM BMPs are determined, and a preliminary design is complete, determine the right-of-way needs for each of the following categories:

- Temporary Construction Easements.
- Occasional Flowage Easements.
- Drainage Easements.
- Channel Easements.
- Slope Easements.
- Fee Simple Acquisitions.

F. Hydrologic Analysis. Hydrologic analyses of the drainage area associated with the project under the following assumed conditions may be necessary to determine the impact on the project:

- Pre-construction - Evaluate stormwater runoff prior to disturbance.
- Construction - Evaluate stormwater runoff during disturbance.
- Post-construction - Evaluate stormwater runoff resulting from additional impervious surfaces after the project is finished.

For most construction E&SPCs the 2-year design storm should be used. If the project is in a Special Protection or High Quality/Exceptional Value Watershed, a greater return period may be warranted. For example, a 5-year design storm is required for temporary channels in special protection waters; if the channels are permanent then a minimum 10-year design storm is required. Also refer to Publication 13M, Design Manual, Part 2, *Highway Design,* Chapter 10 to determine minimum design requirements.

Refer to the specific BMP design details in Section 12.4 through Section 12.6 for additional guidance on calculation of flows. For additional guidance refer to Publication 13M, Design Manual, Part 2, *Highway Design*, Chapter 10 and Chapter 7, *Hydrology*.

G. BMP Selection. Table 12.3 summarizes E&SPCs and can provide the designer with guidance when selecting BMPs for a project. The classifications of high, moderate, and low are relative to other BMPs listed in the table. "Varies" classification indicates variance based on independent product selection within that BMP category.

Table 12.3 BMP Selection

		Initial Cost	**Construction Labor**	**Maintenance**	**Functional Longevity**
12.4	Stabilization Methods				
12.4.A	Seeding & Mulching	Low	Low	Low	Varies
12.4.B	Rolled Erosion Control Products (RECP)	Varies	Varies	Varies	Varies
12.4.C	Spray on Mulches	Low	Low	Low	Varies
12.4.D	Geocell Slope Confinement	Moderate to High	Moderate	Low	Permanent
12.4.E	Articulated Concrete Block Revetment System (ACBR)	Moderate to High	Moderate	Low	Permanent
12.4.F	Gabions	Moderate to High	High	Low	Permanent
12.5	General E&SPCs BMPs				
12.5.A	Rock Construction Entrance	Moderate	Moderate	Moderate	Varies
12.5.B	Rock Filter Outlet	Low	Low to Moderate	Moderate	Varies
12.5.C	Compost Filter Sock	Low to Moderate	Low	Moderate	Varies
12.5.D	Compost Filter Berm	Low to Moderate	Low	Moderate	Varies
12.5.E	Silt Barrier Fence	Low to Moderate	Low to Moderate	Moderate	Varies
12.5.F	Heavy Duty Silt Barrier Fence	Moderate	Moderate	Moderate	Varies
12.5.G	Vegetative Filter Strips for E&SPC	Low	Low to Moderate	Low	Varies
12.5.H	Pumped Water Filter Bag	Moderate	Moderate	Moderate	Varies
12.5.I	Temporary Slope Pipe	Moderate	Moderate	Low	Varies
12.5.J	Storm Inlet Protection	Low	Low	Moderate	Varies
12.5.K	Outlet Protection: Rock	Moderate	Moderate	Moderate	Varies
12.5.L	Outlet Protection: Stilling Well	High	Moderate to High	Moderate	Permanent
12.5.M	Diversion Ditch	Moderate	Moderate	Moderate	Varies
12.5.N	Channel Lining	Varies	Varies	Varies	Varies

Table 12.3 BMP Selection (continued)

		Initial Cost	**Construction Labor**	**Maintenance**	**Functional Longevity**
12.5.O	Rock Barrier	Moderate	Moderate	Moderate	Varies
12.5.P	Sediment Trap (Embankment)	Moderate	Moderate	Moderate	5 years
12.5.Q	Sediment Trap (Riser)	Moderate to High	Moderate to High	Moderate	5 years
12.5.R	Sediment Basin	High	Moderate to High	Moderate	5 years
12.6	In Channel Erosion Controls				
12.6.A	Bypass Channel With Non-Erosive Lining	Moderate to High	Moderate to High	Moderate	Varies
12.6.B	Temporary Stream Diversion: Flume Through Work Area	Moderate	Moderate	Moderate	Varies
12.6.C	Temporary Stream Diversion: Pump Around In-Channel Work Area	Moderate	Moderate	Moderate	Varies
12.6.D	In-Stream Cofferdam	Moderate	Moderate	Moderate	Varies

H. NPDES Permit Preparation. The NPDES Permit for Stormwater Discharges Associated with Construction Activities can be either a General Permit or an Individual Permit. Document preparation has been designated under PA Code, Title 25, Chapters 92 and 102. The following is a list of documents that are required for the type of permit that is being sought.

- General Permit:
  - Notice of Intent Form.
  - Worksheets (attached to permit).
  - Location Map.
  - Municipal Notification (Including proof and Land Use documentation).
  - PNDI Clearance.
  - E&SPC Plan and Narrative.
  - PCSM Plan and Narrative.
  - Permit Checklist.
  - Permit Fees (these are waived for PennDOT).

- Individual Permit (same as General Permit plus the following):
  - Application for Individual Permit (same form as the NOI).
  - Antidegradation Analysis Module (part of the permit form).
  - General Information Form (GIF).
  - Cultural Resource Notice.

Refer to Chapter 4, *Documentation and Document Retention,* for required documentation and document retention and Chapter 6, *Data Collection,* for required data collection for the NPDES permit.

I. Erosion and Sediment Pollution Control Narrative Preparation. As per requirements set forth under PA Code, Title 25, Chapter 102, when applying for an NPDES construction permit, a written narrative must accompany the permit. The narrative includes all backup documentation needed to substantiate the E&SPC Plans (e.g., design computations). Refer to Chapter 4, *Documentation and Document Retention,* for required documentation and document retention and Chapter 6, *Data Collection,* for required data collection for the erosion and sediment pollution control plan. The suggested narrative outline is as follows:

1. Project Description – A brief but detailed overview of the project, total disturbance and time frame.

2. Location and classification, per PA Code, Title 25, Chapter 93, of Waters of the Commonwealth that may receive runoff from within the project site.

3. Existing topographic features of the project site and immediate surrounding area.

4. Types, depths, slope, locations, and limitation of the soils within the project area.

5. Characteristics of the earth disturbance activities, including past, present and proposed land uses along with the proposed alterations of the project site.

6. Amount of runoff from the project area and upstream watershed area.

7. Description of the location and type of perimeter and onsite BMPs used before, during and after earth disturbance activity.

8. Sequence of BMP installation and removal in relation to the scheduling of earth disturbance activities prior to, during, and after earth disturbance activities.

9. Maintenance program for all temporary and permanent BMPs.

10. Procedures to ensure that the proper measures for the recycling or disposal of materials associated with or from the project site will be undertaken in accordance with PA DEP regulations.

11. Appendices: Location map (USGS) and all supporting calculations organized by BMP type.

12.4 STABILIZATION BMPS

Stabilization BMPs are used to stabilize unvegetated slopes after the earth disturbance is completed. They are generally not used as a BMP during construction activities.

A. Seeding and Mulching. Seeding and mulching are methods for temporary or permanent stabilization of disturbed earth. Mulch helps to protect the soil from the impact of rain droplets that can dislodge the soil. Mulches are also used to protect the soil and create a better seed germination environment. Mulches will biodegrade, enrich the soil, and improve vegetative growth.

Seeding should be applied after earth moving activities have ceased and when environmental conditions allow proper seed germination and growth. Refer to Publication 13M, Design Manual, Part 2, *Highway Design,* Chapter 13 for application guidance. Mulching can be done alone as a temporary erosion protection measure, but seeding must always be accompanied by mulching or a rolled erosion control product.

Refer to Publication 408, *Specifications* for construction guidance. Non-organic mulches used for temporary soil protection may need to be removed in order to establish the finished grade and designated surface treatment. Seed and mulch should be reapplied to bare soil areas if the vegetative cover growth is below uniform 70% coverage, before construction completion.

B. Rolled Erosion Control Products (RECP). Erosion control blankets and mats, collectively known as RECPs, include a wide range of natural and synthetic materials. RECPs reduce soil erosion and, where vegetative cover is established, act as a soil stabilizer. RECPs can be used to provide temporary or permanent stabilization. RECPs are an alternative to mulch. They are effective for stabilizing soils on steep to mild slopes and newly landscaped areas. RECPs hold soil particles in place, reduce the impact force of water droplets on soil particles, and retain soil moisture to promote seed germination. RECPs are also effective in protecting waterways for temporary stabilization until vegetation is established or as permanent stabilization in water channels. There are many product options available for RECPs. Selecting the right one is based on many factors, such as:

- Duration.

- Location parameters, such as slope, soil and hydraulic conditions.
- Relative costs to purchase, install and maintain.
- Aesthetics.
- Rate of degradation.

Most RECPs are considered temporary (i.e., not expected to remain functional for the life of the facility). Some turf reinforcement mats are permanent. RECPs should be used in lieu of mulching on soil slopes steeper than 1V:3H (3H:1V).

RECPs should be considered in the following situations:

- Slopes steeper than 1V:3H (3H:1V).
- Earth disturbance occurs within 15 m (50 ft) of a surface water (e.g., stream crossings, wetlands, ponds, etc.), especially if site conditions are not favorable for conventional erosion and sediment control BMPs. (Note: E&SPC Plans must address how erosion from disturbed areas will be controlled before the RECP is installed).
- Where soil conditions (e.g., low fertility, low moisture, erodibility, etc.) make revegetation difficult.
- As temporary mulching to protect seeded areas from washouts.
- Areas where it is desirable to accelerate seed germination and growth.
- Areas prone to high winds.

RECPs are NOT effective in the following situations:

- Slump prone areas. When slope stability problems are anticipated or encountered, appropriate counter measures such as reducing steepness of slope, diverting upslope runoff, reducing soil moisture, loading the toe, or buttressing the slope should be considered.
- Areas that will be mowed.
- Areas that contain rocky soil such that proper staking cannot be achieved.

1. Organic Erosion Control Blankets/Mats (ECBs). These items are bio-degradable mesh mats, nonwoven blankets or organic materials covered on one or both sides with netting. The blankets/mats provide a temporary mulching effect which helps to protect the seeded area from washouts by reducing the impact of water droplets striking the soil while helping to accelerate seed germination and growth.

ECBs do not provide turf reinforcement enhancement and are not designed to permanently control erosion on unvegetated surfaces. Use ECBs on gentle to moderate slopes and in low velocity and low flow swales or channels. The life span of these materials generally does not exceed two years.

- Erosion Control Mats. Bio-degradable mesh netting used in conjunction with separate mulch application to retain the mulch and the seeded soil in place until grass cover is established. Expected useful life is one year.

- Erosion Control Mulch Blankets. Blankets are comprised of organic, bio-degradable mulches attached on one side to netting. Separate mulch application is not required. Expected useful life is from one to two years depending on the organic material comprising the mulch layer.

- High Velocity Erosion Control Mulch Blankets. Blankets contain an organic bio-degradable mulch layer attached on both sides with netting. Separate mulch application is not required. Expected useful life is from one to two years depending on the organic material comprising the mulch layer.

2. Synthetic Erosion Control and Revegetation Mats (ECRMs). Synthetic material mats are generally stronger than ECBs and will provide longer-term erosion control protection. Use where more than two years are needed to establish a good grass cover. ECRMs are generally designed for mulching and protection of steeper slopes and channels with moderate flow velocities. Separate mulch application is not required.

ECRMs are generally thinner than turf reinforcement mats and lack the three dimensional void space necessary for soil filling. Excessive stretching can occur due to limited dimensional stability of some material.

3. Turf Reinforcement Mats (TRMs). These synthetic, three-dimensional, high tensile strength and dimensionally stable mats are usually thicker than 13 mm (0.5 in) with greater than 90% voids. The TRMs are designed for permanent erosion control by providing soil armoring, soil retention, mulching, and turf reinforcement. TRMs are resistant to biological and chemical degradation.

The mat material becomes synergistically entangled with the grass stems, rhizomes and roots so that the reinforcing effect is enhanced over that of the grass or the mat alone. Use in ditches, channels and steeper slopes or auxiliary waterways.

Table 12.4 RECP Selection (Typical)

	Maximum Slope	**Functional Longevity**	**Maximum Velocity***		**Maximum Shear Stress***	
			m/s	**ft/s**	**N/m^2**	**lb/ft^2**
Erosion Control Mats (ECM)	2V:1H	1 year	2.4	8	24	0.5
Erosion Control Mulch Blankets (ECB)	2V:1H	1 year	1.8	6	72	1.5
High Velocity Erosion Control Mulch Blankets	1V:1H	1 year or longer	2.4	8	96	2
Turf Reinforcement Mat (TRM)	1V:1H	Permanent	3.7	12	240	5
Erosion Control and Revegetation Mat (ECRM)	1V:1H	1 year or longer	2.1	7	191	4

* These are average values. Refer to the manufacturer's literature for values specific to the product.

The data provided in Table 12.4 are average values of products approved by PennDOT for each category of RECP represented. Velocity and shear stress values may vary between specific products within a given category. The velocity and shear stress values are based on unvegetated surfaces.

The design consists of selecting the appropriate product for the situation. Review the following steps and refer to Table 12.4 to select the best product for the project. Note that all of the products in Table 12.4 are appropriate for channel lining.

- Determine the slope of the unstabilized areas requiring protection.
- Determine the duration the protection is needed.
- Refer to Chapter 8, *Open Channels,* when it is desired to use an RECP for channel or ditch protection.

Refer to Publication 408, *Specifications*, Section 806.3 for construction methods. The performance of any RECP depends on surface preparation to ensure continuous contact of the blanket with the underlying soil as well as following the installation techniques of terminal ends, material joints, overlaps and edges at the crest, toe and sides. The installation instructions provided by the manufacturer of the product should also be followed. If these instructions are not available, a typical anchoring method may be appropriate. Use care that the plans show clear guidance for blanket/mat orientation, check slots, anchoring, and anchoring patterns. If washouts occur, determine the cause of washout and consider replacing RECP with one that has a higher maximum shear stress value or using an alternative BMP.

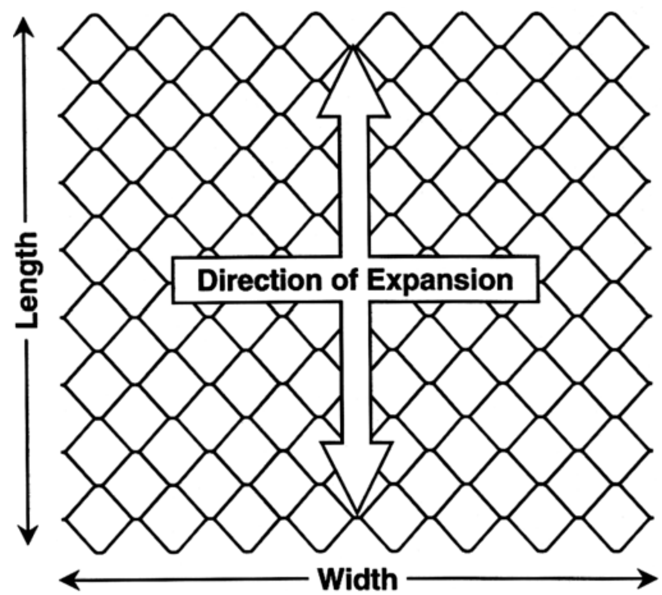
C. Spray on Mulches. Mulching, when applied with seeding, is a method to provide temporary or permanent stabilization for disturbed earth. Spray on mulching is a method of applying mulch, in most cases along with seed and fertilizer, as a controlled spray from a hydraulic tanker truck. Advantages of spray on mulching include ease of applying in a uniform product distribution, ability to apply in remote locations without disturbance of the treated landscape, a faster germination rate of the seed due to a specifically developed micro-environment of the mix, and a higher moisture retention content. Spray on mulches can be used in lieu of RECPs on slopes flatter than 1V:3H (3H:1V).

Vegetated areas are considered to be permanently stabilized when a uniform 70% vegetative cover of erosion resistant perennial species has been achieved. Prior to completion of construction, the spray on mixture should be reapplied on any bare soil areas or locations where the 70% vegetative growth cover is not achieved.

For application guidance, refer to Publication 13M, Design Manual Part 2, *Highway Design*, Chapter 13. For construction consultation, refer to Publication 408, *Specifications* and Publication 35, *Approved Construction Materials* (Bulletin 15).

D. Geocell Slope Confinement. A geosynthetic cellular confinement system made of high density polyethylene (HDPE) used to provide permanent stabilization for steep side slopes and protect against erosion. Geocell slope confinement systems may be used for slope and swale protection to prevent embankment erosion on cut/fill slopes that do not require mowing. "Geocell" is a generic term for a geosynthetic cellular confinement system manufactured from HDPE. In place, geocell has the appearance of a honeycomb structure. The cells are filled with one of a variety of infill materials. The completed confinement system armors, protects, and stabilizes the underlying strata from the erosive effects of wind and water. Geocell has the ability to resist erosive forces by minimizing the downward migration of infill embankment materials.

Figure 12.1 Geocell Slope Confinement System



Geocell is covered by U.S. Patent 4,797,026. Manufacturers wishing to produce geocell must obtain a license from the patent holder during the term of the patent. Publication 35, *Approved Construction Materials* (Bulletin 15) lists suppliers of geocell manufactured by licenses under the U.S. Patent.

Geocell offers the following advantages over traditional rolled erosion control products:

- A wide range of installation temperatures.
- Lightweight, 100 mm (4 in) depth geocell is suitable for most erosion control applications.
- Requires no specialized equipment or labor for installation.
- Flexibility - able to conform to minor inconsistencies in subgrade.
- Utilizes readily available topsoil, Class C concrete, and aggregates (AASHTO No. 8, 67, 57 and PennDOT 2A) for backfill.
- Resistance to corrosion or degradation over time.

Geocell is suggested for use on steep embankment slopes for protection against erosion; however, when used according to this BMP, Geocell does not increase the stability of the underlying slope. Geotechnical engineering analyses must show that the protected slope is stable prior to consideration of a geocell system using this BMP. This BMP is not suitable for use on natural slopes that are steeper than the angle of repose of the underlying slope material. Do not use geocell to correct erosion problems with a design flow velocity greater than 6 m/s (20 ft/s). When using geocell with a topsoil to topsoil (with plantings) interface, do not use geotextile lining. RECPs can be used to promote seed propagation when topsoil is used as an infill material as an alternative. For design flows greater than 3 m/s (10 ft/s) consider using ACBR or rock.

Geocell applications may include:

- Embankment slope protection.
- Swale surfaces.
- Cut slopes.

The data requirements and calculations for design of a geocell protected surface for cut and fill embankment surfaces include:

- Parameters for stability analysis and dimensional data that define the layout and geometry of the system:
    - Slope/Dimensions: Slope V:H (H:V) and slope length.
    - Soil Properties:
        - Soil Description: angle of internal friction (degrees), cohesion ($kN/m^2(lb/ft^2)$), unit weight ($kN/m^3(lb/ft^3)$).
        - Primary Infill Description: angle of internal friction (degrees), cohesion ($kN/m^2(lb/ft^2)$), unit weight ($kN/m^3(lb/ft^3)$).
    - Hydraulic Conditions: Surface runoff, concentrated runoff, groundwater seepage.
    - Subgrade/Strata Under Geocell System: soil, aggregate, Class 2 - Type B geotextile.
    - Critical Interface for Sliding and Angle of Shearing Resistance: Geocell infill/foundation soil (degrees), geotextile underlayer/foundation soil (degrees).
    - Select Infill such as: topsoil, coarse aggregate (AASHTO No. 67, 57, 8, PennDOT 2A) and Class C concrete.
    - Ground anchoring options such as: stake anchors, crest anchoring, earth anchors, dead-man anchors, tendons and direct burial.
- Determination of cell depth or minimum allowable angle or repose of the infill.
- Determination of allowable interface friction angle from a given minimum interface friction angle and assumed factor of safety.
- Determination of anchorage requirements, if necessary.
- Cost estimate for geocell system.

The following six-step procedure provides a method for the static analysis of system stability using design figures for a defined slope, soil and infill parameters and an appropriate factor of safety for 100 mm (4 in) deep cells and the standard cell size. The procedure compares the downslope force components and the total resisting forces - interface friction, in-plane tensile anchorage, and in-place resistance of anchor components. It should be noted that this design procedure is only for non-perforate cell walls.

Note: Hydraulic effects are NOT considered in this design procedure. Do not use this procedure to design a geocell channel lining for use under submerged flow conditions.

If the combined resistance of the interface friction and stake anchors is sufficient to resist down slope sliding forces (with a suitable factor of safety), no other anchorage such as a crest anchorage is required. For many applications where additional resistance is required, an anchor trench or minimum length of embedment, with soil cover, can be utilized to develop adequate resistance via a crest anchorage.

When tendons are used in addition to stake anchors to develop the required factor of safety, restraint clip pins are required at specified down slope centers to transfer resisting forces to the tendons which in turn transfer the tensile load to the crest anchor system. Since stake resistance is determined independently of the tendon tensile load, the stakes are required to bear against the cell walls.

Various combinations of crest, stake and restraint pin anchor details are shown in Publication 72M, *Roadway Construction Standards*. Determine system stability through static analysis using the following design figures or the equations accompanying the six-step procedure in Table 12.5.

Table 12.5 Six-Step Geocell Static Design Procedure

Step 1	**Determine the Appropriate Cell Depth or Infill Minimum Allowable Angle of Repose**
Cell depth. Using Figure 12.2, determine the minimum angle of repose based on the cell infill material. For applications involving Class C concrete as infill material, angle of repose is not applicable; typically 100 mm (4 in) is an appropriate cell depth. On Figure 12.2, find the intersection point of a vertical line up from the design slope and the horizontal line over from the Infill Material Minimum Angle of Repose. Choose the Geocell depth below the intersection point of the two lines.	
Infill minimum allowable angle of repose. When the Geocell depth is known, move vertically up from the design Slope to the desired cell depth line and horizontally over to the Infill Material Minimum Angle of Repose. Choose an infill material with a minimum angle of repose no less than that determined. For Class C concrete on a Slope, the steepness may be no greater than the angle of repose of the embankment material.	
Step 2	**Apply Factor of Safety to Minimum Interface Friction Angle**
• Determine the Interface Friction Angle from Figure 12.3 or select from Table 12.6 the appropriate Interface Description and apply the appropriate Factor of Safety (FOS) to the Minimum Interface Friction Angle. The Allowable Interface Friction Angle is then used in Step 3. • The remaining steps of this procedure are illustrated with an assumed FOS of 2.50.	
Step 3	**Determine Required Resistance of Staking Array for 100 mm (4 in) Cell Depth**
• Determine the Required Stake Array Resistance, from Figure 12.4, by moving vertically up from the Slope to the Selected Interface Description (suggested Allowable Interface Friction Angle with applied FOS) and over to the Required Stake Array Resistance. • Refer to Table 12.6 for assumed unit weight and friction angle for each Interface Description. If the actual interface is different than those presented, use the one with the closest values or use the equations provided to perform a site specific analysis.	
Step 4	**Determine Maximum Downslope Stake Spacing**
Using the Required Stake Array Resistance determined in Step 3, the Maximum Downslope Stake Spacing is determined as a function of Slope and Interface Description. Note: The maximum downslope spacing is not to exceed 2.4 m (96 in). This maximum is equal to 12 cells.	
Step 5	**Determine Individual Stake Resistance for Standard Cell**
• Based on the Required Stake Array Resistance determined in Step 3 and considering the Maximum Downslope Stake Spacing as determined in Step 4, determine the Required Individual Stake Resistance by using a downslope spacing which does not exceed the Maximum Downslope Stake Spacing. • Stakes are to be placed in every other cell across the Geocell section. Down slope spacing can vary with infill material. Each cell down is 200 mm (8.0 in). • The solution presented in the Figure 12.6 assumes a 2 cell across by 3 cell down staking pattern for each Interface Description. Use the equations to calculate the Required Individual Stake Resistance for other staking patterns. Note: changing the staking pattern will affect the actual stake length determined in Step 6.	
Step 6	**Determine Actual Stake Length**
• Determine the Total Stake Length (including in-ground length plus 100 mm (4 in) to top of cell) from Figure 12.7 using the staking pattern developed in Step 5 and a typical roadway embankment with the following parameters: o Embankment Soil Unit Weight = 19 kN/m^3 (120 lb/ft^3) o Angle of Internal Friction = 30 degrees • Consideration should be given to the actual Embankment Soil Unit Weight and Angle of Internal Friction, if known, prior to calculation of the Total Stake Length. • J-Pin Stakes, Straight Stakes, and Clip Stakes are three types of stake anchors available. Stakes are #4 rebar. Add additional length for J-Pin type stakes (see detail on Figure 12.7).	

Figure 12.2 Relationship Between Cell Depth, Slope Angle and Infill Material Minimum Angle of Repose

STEP 1

$$\phi = \beta - \arctan\left(\frac{d - d_e}{L}\right) \text{ or}$$

d = L tan (β - ϕ) + d_e where:

ϕ = *Minimum angle of repose of the infill material, degrees*

β = Slope angle, degrees

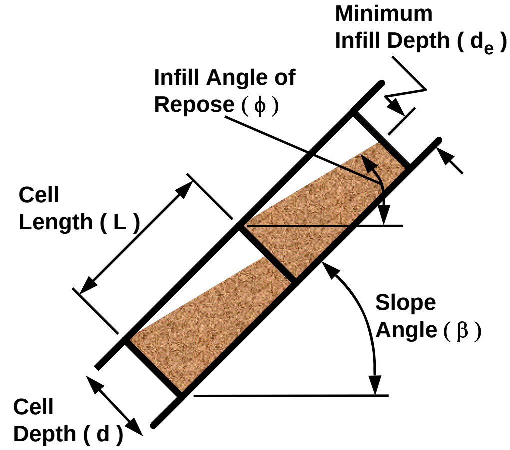
d_e = Minimum acceptable depth of infill against the up-slope wall of the cell, mm (in). This should be 0.5 times the cell depth.

For this case,

$$\phi = \beta - \arctan\left(\frac{0.5d}{L}\right)$$

L = Up/down slope-length of the cell, mm (in)
= 8" (assumed cell length)

Note for β: The table below uses slope (H:V) where β = arctan (V/H)= $\tan^{-1}$(V/H)



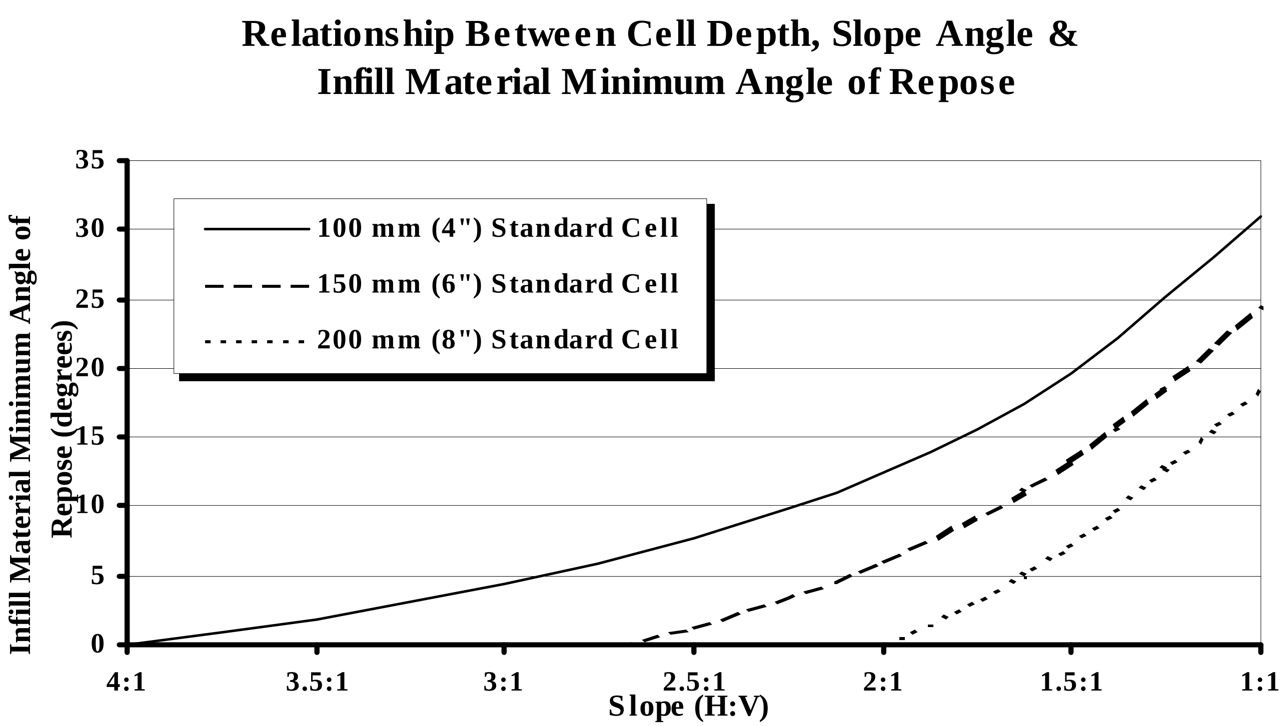


Table 12.6 Typical Soil and Interface Characteristics

STEPS 2 and 3

Values for Cell Infill Material Minimum Angle of Repose are to be used in Step 1 to determine the appropriate cell depth.	**Cell Infill Material**			**Minimum Angle of Repose (degrees) ***
	Topsoil			22
	Gravel			30
	Crushed Stone			34
	Class C Concrete			NA
Values for Interface Friction Angle are to be used in Step 3 after applying the appropriate Factor of Safety.	**Interface Description**	**Unit Weight**		**Minimum Interface Friction Angle**
		kN/m^3	**lb/ft^3**	**degrees ***
	Topsoil to Topsoil (with plantings)	21.2	135	22
	Topsoil over Geotextile	21.2	135	18
	Gravel (2A) over Geotextile	22.0	140	26
	Stone (No. 8) over Geotextile	14.7	94	30
	Concrete over Geotextile	22.7	145	30
	Geotextile over Clay (worst case)	22.7	145	18
Values for Embankment Soil Angle of Internal Friction are to be used in Step 6.	**Embankment Soil**			**Angle of Internal Friction (degrees) ***
	Well/Poorly Graded Gravels (GW/GP)			34
	Silty Gravels (GM)			30
	Clayey Gravels (GC)			28
	Well Graded Sands (SW)			34
	Poorly Graded Sands (SP)			32
	Silty Sands (SM)			28
	Sand – Silt Clay (SM-SC)			26
	Clayey Sands (SC)			26
	Silts/Clayey Silts (ML)			22
	Silts/Clayey Silts (ML-CL)			22
	Clays/Clayey Silts (CL/MH)			20
	Clays (CH)			17

*__NOTE__: Friction angle values are maximum presumptive values for preliminary design of geocell infill only. If actual conditions indicate a difference from presumed conditions, laboratory testing shall be conducted to confirm the design.

Figure 12.3 Allowable Interface Friction Angle with Applied FOS

STEP 2

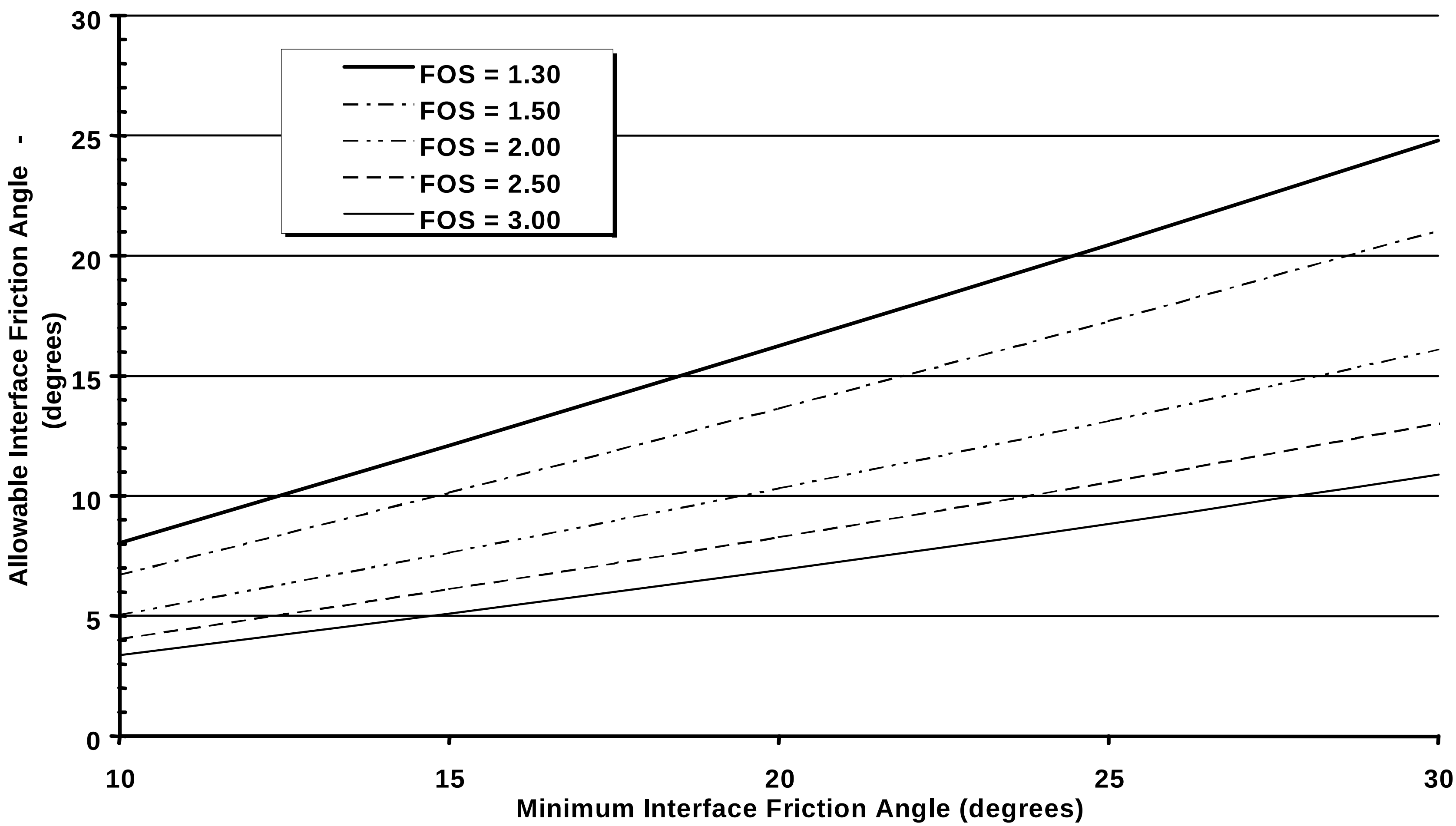


Figure 12.4 Required Stake Array Resistance for Various Slopes and Interface Descriptions with 100 mm (4 in) Cell Depth

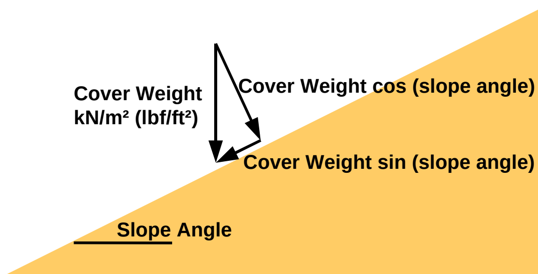
STEP 3

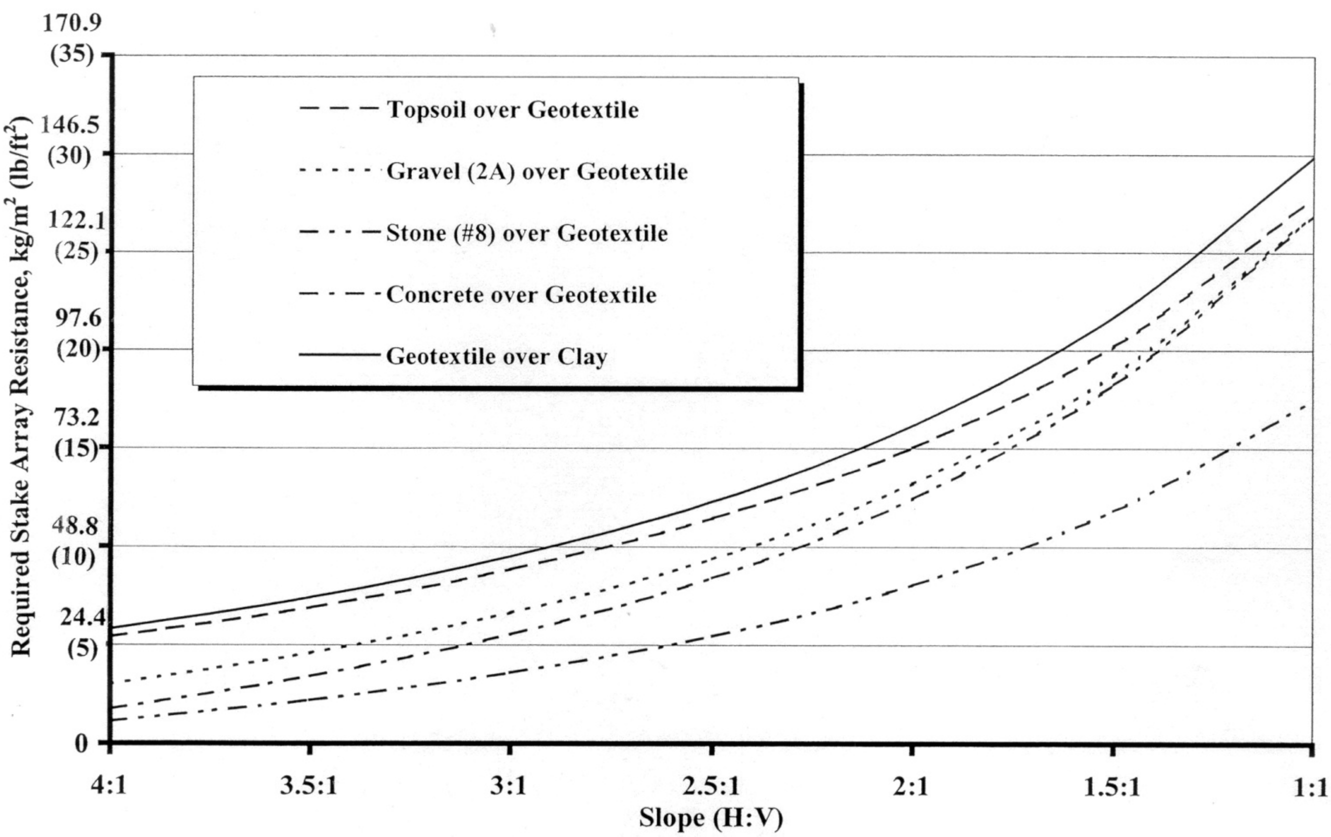
$$RSR_a = W_c \sin\beta - W_c \cos\beta * \tan\left(\frac{\phi}{FOS}\right)$$

Where:

- RSR_a = Required Stake Resistance of the stake Array, kg/m² (lb/ft²)
- W_c = Cover weight, kg/m² (lb/ft²) = $d\gamma$
- d = m (ft) Cell depth
- γ = Unit weight of the infill soil, kN/m³ (lb/ft³)
- β = Slope angle, degrees
- ϕ = Minimum Interface Friction Angle at the bottom of the Geocell, degrees
- FOS = Factor of Safety (use 2.5)

Note for β: Figure in Step 3 uses slope (H:V) where β = arctan (V/H)=*tan*$^{-1}$(V/H)





NOTE: The remaining steps of this procedure are illustrated using a FOS value of 2.50.

Figure 12.5 Maximum Downslope Stake Spacing

STEP 4

$MDS = \dfrac{SS_u}{FOS\ RSR_a}$	Where: MDS = Maximum Downslope Spacing, m (ft)* SS_u = Ultimate Long-term Seam Strength 100 mm (4 in) deep *Geocell* section, 3.2 kN/m (220 lb/ft) FOS = Factor of Safety, 2.5 is suggested and used here RSR_a = Required Stake Resistance, kN/m² (lb/ft²) NOTE for SS_u: Each 100 mm (4 in) seam must support 0.712 kN (160 lb) for the long-term test. There are 11 seams in a 2.44 m (8 ft) wide panel. Therefore, for a 100 mm (4 in) *Geocell*, SS_u = 0.712*11/2.44 = 3.21 kN/m (160*11/8 = 220 lb/ft).

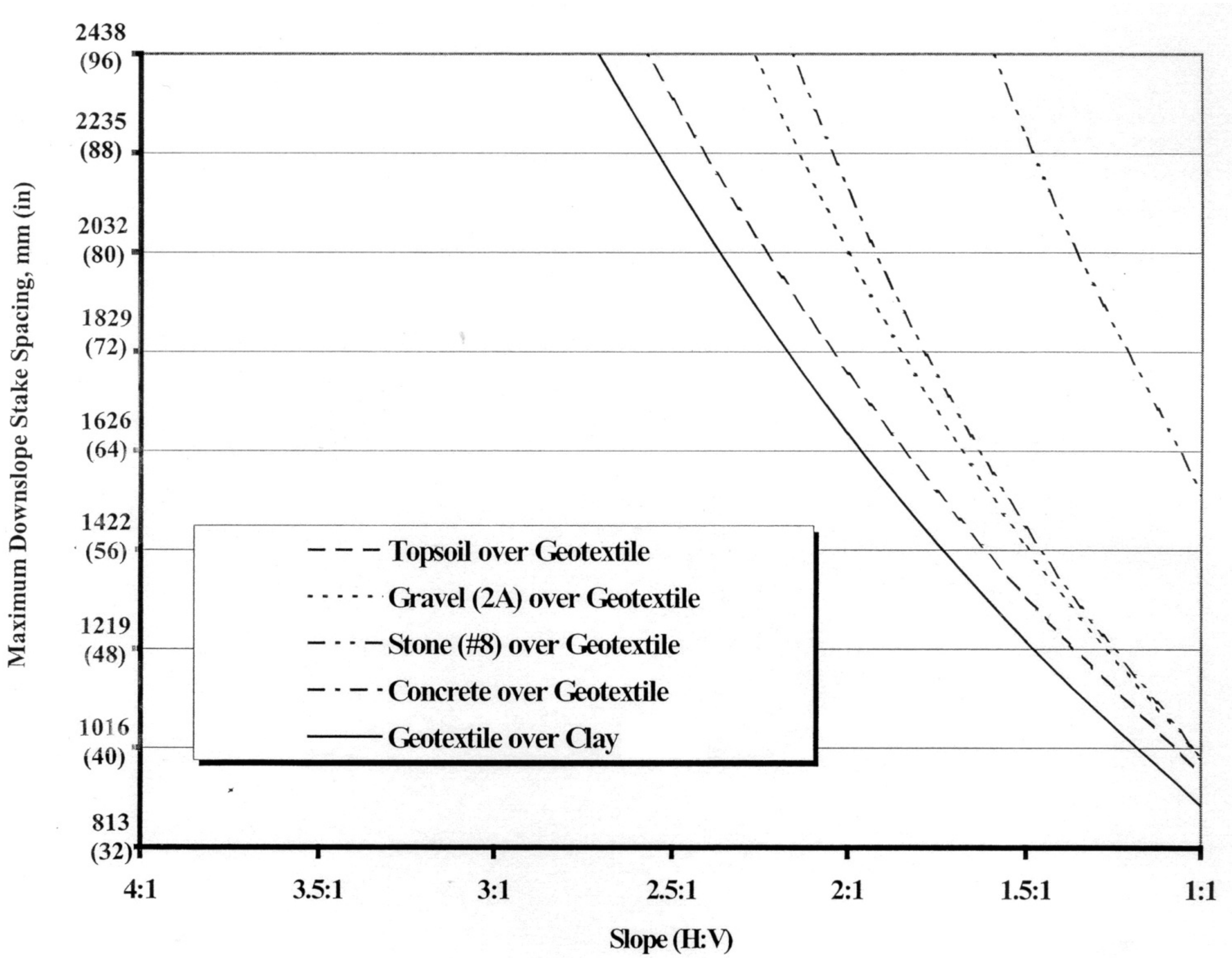


Figure 12.6 Required Stake Resistance for Standard 100 mm (4 in) Cell for 2 Cell Across by 3 Cell Down Staking Pattern

STEP 5

$P_p = RSR_a D_{cs} D_{ds}$	Where: P_p = Required Stake Resistance of the individual stake, N/stake (lb/stake) RSR_a = Required Stake Resistance, kN/m² (lb/ft²) D_{cs} = Cross-slope Spacing number of cells converted to m (ft). D_{ds} = Downslope Spacing number of cells converted to m (ft).

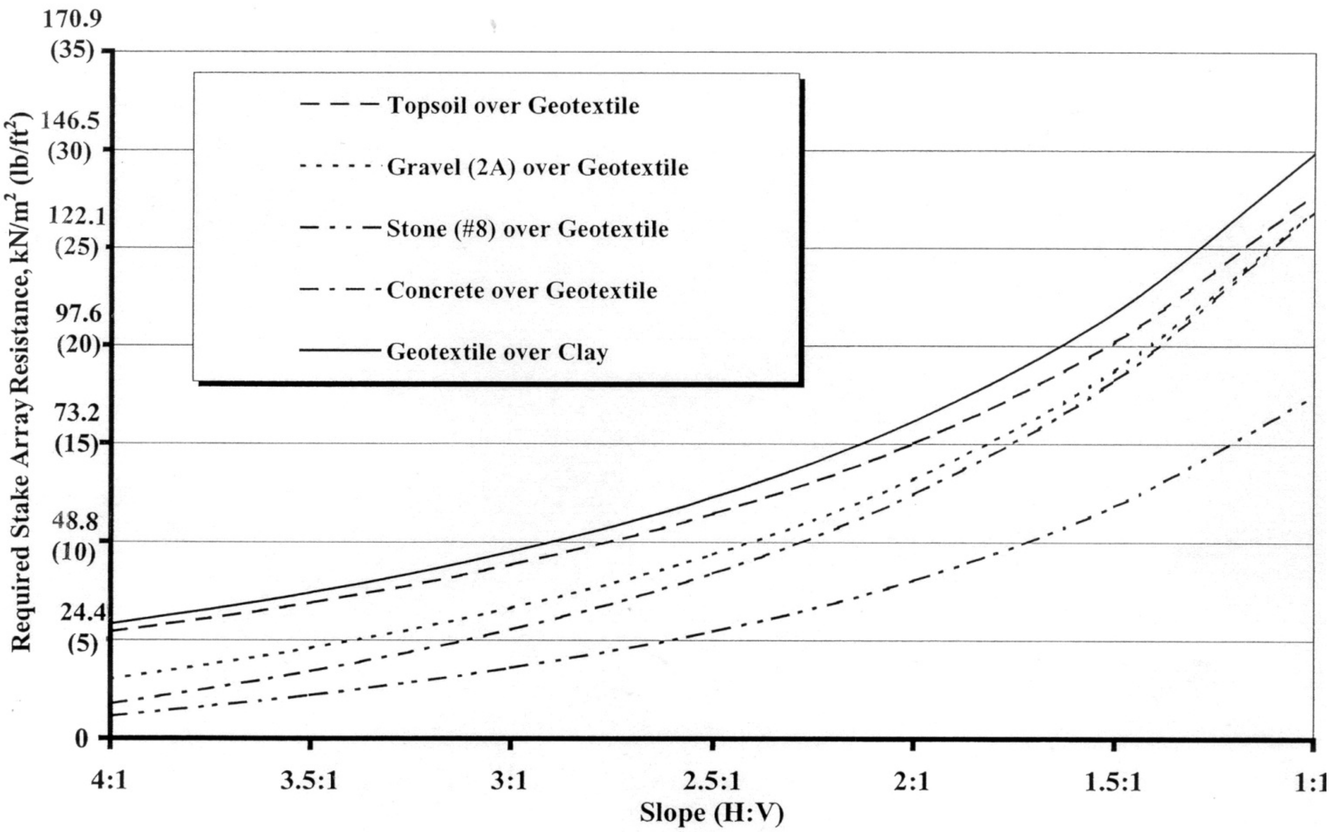


Figure 12.7 Required Stake Length for #4 Rebar Typical Roadway Soil Embankment

STEP 6

Minimum Stake Length l - m (ft) is determined by solving:

$$l = \sqrt{\frac{P_p}{0.5\ d\ \gamma \dfrac{1+\sin\phi}{1-\sin\phi}}}$$

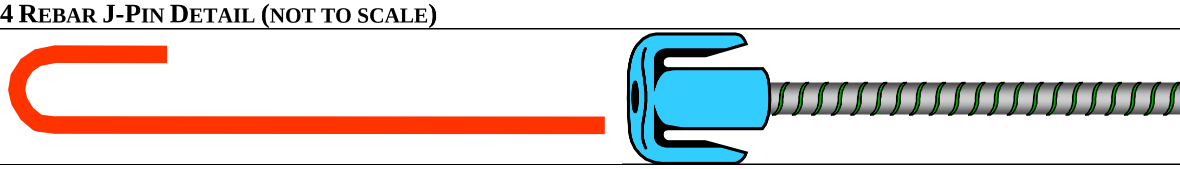
The above is derived from:

$$P_p = 0.5\,\gamma\ d\ K_p\ l^2$$

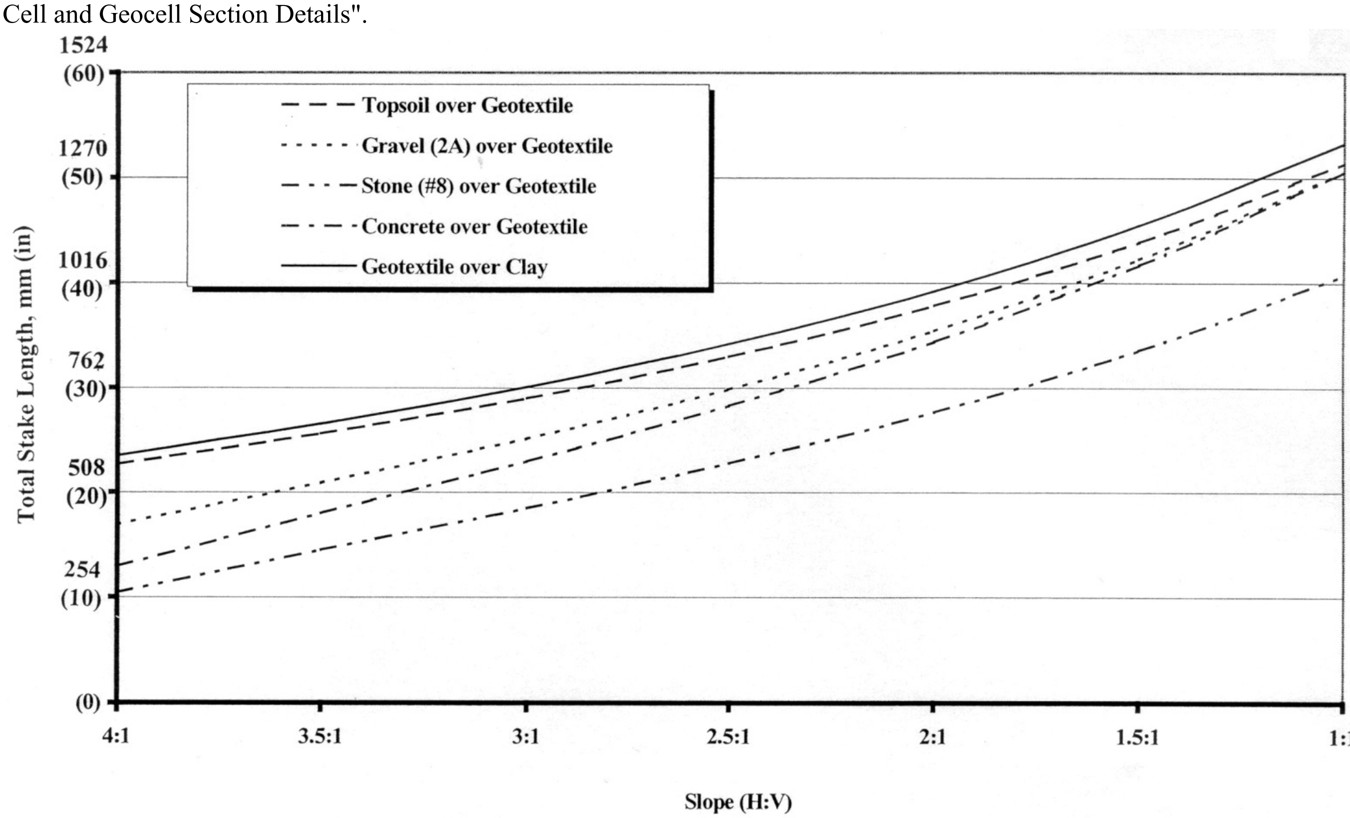
Where:

- l = Stake Length, m (ft)
- P_p = Required per Stake Resistance, kN (lb)
- d = Stake Diameter, m (ft)
- γ = Embankment Soil Unit Weight, kN/m³ (lb/ft³)
- $\varnothing$ = Angle of Internal Friction of the Embankment Soil, degrees
- Kp = Coefficient of Passive Earth Pressure = $\tan^2(45+\frac{\phi}{2})$

#4 REBAR J-PIN DETAIL (NOT TO SCALE)



For additional stake options, refer to Publication 72M, *Roadway Construction Standards* entitled "Slope Protection, Geocell Cell and Geocell Section Details".

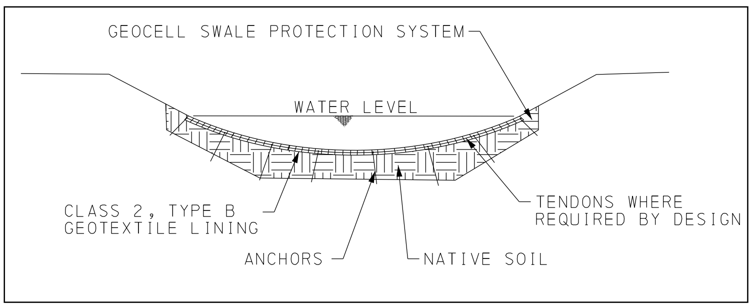


To determine site slope cover stability under hydraulic conditions, consult the appropriate geocell manufacturers or use recognized methods. Suggested geocell infills for swale protection systems are as follows:

Table 12.7 General Guidelines for Selection of Swale Infill Materials

Infill	**Peak Flow Velocity**		**Infill Material**
	less than		
	m/s	**ft/s**	--
Soil with Grass Cover[1]	4.5	15	--
Aggregate	1	3.3	PennDOT 2A
	2	6.6	AASHTO No. 57 or No. 67
Concrete	6	20	--
[1]Swale side slopes above high water level (see Figure 12.8)			

Figure 12.8 Basic Geocell Swale Protection System



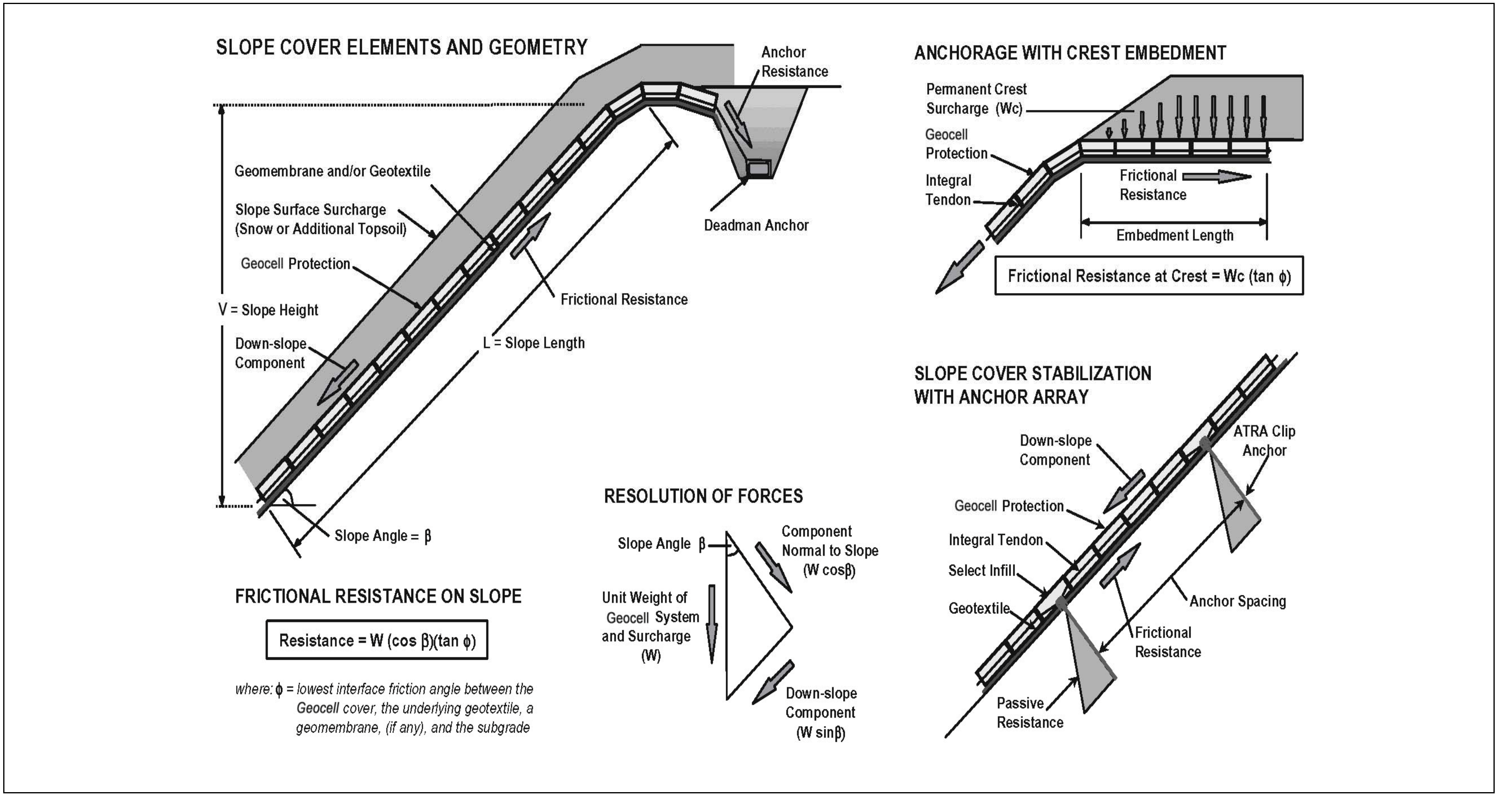
1. General Considerations. A stability analysis of the geocell system in non-hydraulic conditions will determine if the system's weight exceeds the frictional resistance between the system and the subgrade or underlayer (Figure 12.9). If this is the case, supplemental anchorage will be necessary. The integral tendons of the geocell system in conjunction with anchor assemblies then become a critical component to retain the system.

A common method of securing geocell protection on steep slopes involves installation of structural anchors in a uniform grid pattern throughout the cover layer. Slope geometry, subsoil, protection type and possible surcharge loads determine the size, material type and distribution of the anchors. The system requires securing staked anchors or other anchor types to the integral tendons by forming an appropriate knot in the tendon at each anchor location. Driven anchors are in the proper position in the ground when the bottom of the clip or stake end cap is flush with the underside of the geocell section. This ensures that anchors do not project above the surface of the protection after filling the cells.

The tensile resistance of the tendoned geocell system governs the maximum allowable down-slope spacing of individual surface anchors. The size and shear capacity of each anchor dictates the density of the overall anchor array. Use the design procedure in this section or analytical methods provided by the manufacturer to determine complete anchor details. The analysis shall compare downslope forces, both static and dynamic, and resisting forces due to interface friction, in-plane tensile anchorage, and in-plane resistance of anchors. When installation of an anchor array is impractical, a tendoned geocell system with crest anchorage may be one solution.

When additional anchorage is required to resist concentrated surface flow, which imposes a determined flow velocity, depth of flow and hydraulic shear stress, determine the hydraulic shear resistance of the geocell infill materials and the total tractive force on the system in accordance with a system specific design procedure.

Figure 12.9 Stability Analysis of the Geocell Slope Protection System



2. Geocell System with Vegetated Topsoil Infill. Well-established vegetation is an effective and attractive form of protection for slopes that suffer mild or moderate surface erosion. However, the effectiveness of vegetated covers subject to persistent or concentrated surface runoff may not be acceptable. This type of flow can progressively remove soil particles from the root zone, creating rills and gullies that ultimately destroy the protection. For this reason an erosion control blanket should be used to help promote seed propagation.

The geocell walls, which contain the topsoil infill, form a series of check-dams extending throughout the protected slope. By continuously redirecting flow to the surface, the geocell cell walls prevent normal rill development from concentrated flow cutting into the soil. This mechanism also retards flow velocity and reduces the erosive force of runoff. The individual cells contain and protect a predetermined depth of topsoil and the developing vegetative root zone. Roots readily penetrate through the non-woven geotextile underlayer into the subsoil, creating an integrated, blanket reinforcement throughout the slope surface.

Use vegetated topsoil infill in situations where surface flows are intermittent, of moderate intensity, and of relatively short duration (less than 24 hours). Restrict use to peak velocities of 4.5 m/s (15 ft/s) for short durations with established vegetated cover. Prepare existing ground in accordance with manufacturer installation guidelines. Place a Class 2, Type B, non-woven geotextile underlayer. Place degradable erosion control blankets to protect exposed topsoil and seed to promote rapid establishment of vegetation. Select erosion control blankets in accordance with criteria established by respective RECP manufacturers. Determine slope anchorage requirements in accordance with the design procedure in this section or design analysis tools and methods provided by the Geocell manufacturer.

3. Geocell System with Aggregate Infill. If the slope angle is less than the angle of repose of the aggregate infill, it can effectively protect the slope. Aggregate infill systems are dependent on adequate toe support to prevent undermining of the loose aggregate further up the slope. Hydrodynamic forces of concentrated runoff can erode channels within aggregate infills. Confinement of loose aggregate within geocell systems permits use on slopes steeper than otherwise possible. A wide range of aggregate infill/slope geometry combinations can be accommodated by selecting the appropriate cell size and cell depth for the aggregate in question (see Figure 12.10). Aggregate-filled geocell slope protection can stand up to more intense sheet-flow conditions than unconfined aggregate cover layers. The cell walls prevent channeling that could develop within the cover layer by limiting localized flow concentrations and increasing resistance to hydraulic shear stresses.

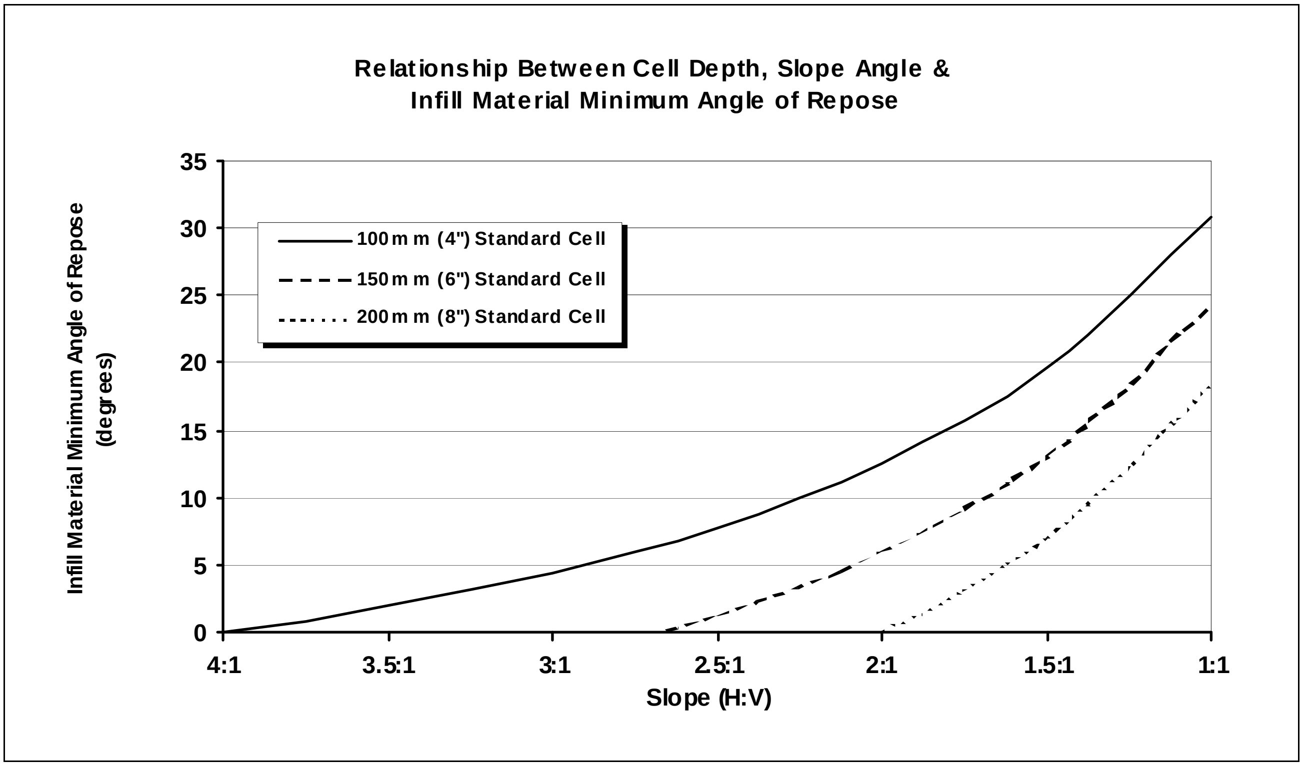
Loose aggregate infill materials can be effective in geocell systems for surface flows less than 2 m/s (6.6 ft/s). Use a Class 2, Type B, non-woven geotextile underlayer to prevent loss of fine-grained subsoil particles.

The required cell depth for aggregate infill on steep slopes relates to the natural angle of repose of the aggregate and the slope angle. Figure 12.10 shows minimum suggested cell size and depth for several aggregate types relative to angle of repose and slope angles. If stake anchors cannot meet design requirements, place tendons through every cell to increase the superimposed weight of the aggregate infill bearing directly on the tendon system. Determine slope anchorage requirements in accordance with the design procedure in the section, design analysis tools available from the company, or recognized engineering practice.

4. Geocell System With Concrete Infill. Poured concrete provides a hard, durable protection for slopes. Traditional concrete slab construction requires: steel reinforcing, forms for discrete isolated sections to prevent structural cracking, and construction joints to accommodate shrinkage from drying and thermal expansion/contraction. The potential for damage to traditional construction, as discussed in the previous sections, increases if permanent or seasonal subgrade deformations occur. These factors increase installed costs. Concrete filled geocell reduces these costs and kinds of inherent problems.

Infilling the cells of geocell with ready-mixed concrete produces a durable, erosion-resistant slope cover of uniform thickness which retains its flexibility and maintains an ability to conform to potential subgrade movement. This type of construction avoids compacted granular bedding layers, necessary with conventional poured concrete slabs. Selecting the quality, surface finish and thickness of the concrete allows the designer to meet specific design needs. A non-woven geotextile filter fabric with custom weep holes, if necessary, can assure effective subgrade drainage and subsoil filter protection. Normal drying shrinkage of the concrete infill gives the entire slope surface an ability to drain groundwater from the subgrade. The uniformly distributed shrinkage also imparts a degree of flexibility to the system. Concrete placement either by pumps, boom-mounted skips or direct discharge from ready-mix trucks is possible.

Figure 12.10 Geocell Selection for Various Slopes and Cell Depth



Flexible concrete forming techniques can accommodate complex slope geometry. Evaluate concrete infill for slopes that are subject to surface flows up to a maximum of 6 m/sec (20 ft/s). Use Class C concrete. Specify appropriate surface finishes (trowel, broom or rake), in order to meet specific aesthetic or surface friction requirements. Embed aggregates or gravel into the surface of wet concrete infill to produce a variety of textures, colors, and surface finishes as desired.

5. Cell Size and Depth Selection. Determine cell depth based on the design procedure. Under hydraulic conditions, consider potential tractive or uplift forces on the slope protection in accordance with the system specific design procedure. Greater cell depth increases the unit weight of the system as well as the flexural stiffness and uplift resistance of the system.

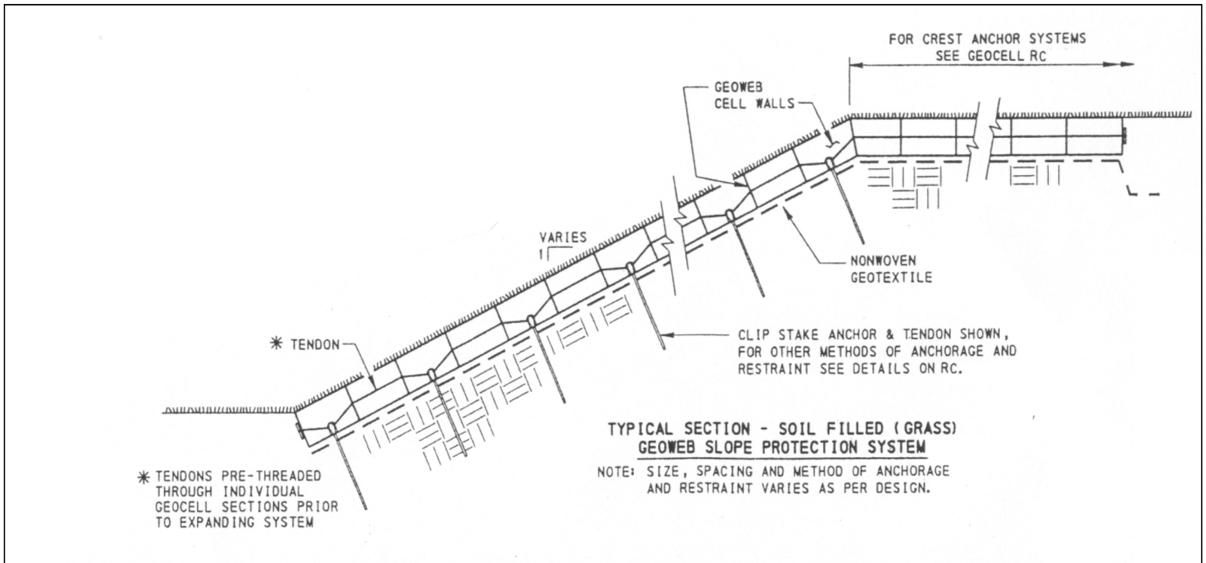
6. Surface Anchorage. Determine what slope anchorage requirements are necessary in accordance with the design procedure in this section or with system-specific design procedures provided by the manufacturer.

The complete geocell system is a multi-component system that includes:

- Geocell panels or mats (plastic cellular panels or mats stapled together).
- Infill material.
- Stakes with a design specific length and pattern of placement.
- Design specific tendons and/or anchor assemblies, when necessary.
- Class 2, Type B geotextile (only required when aggregate is used as a infill material).
- Erosion control blankets (when topsoil is used as a infill to promote seed propagation).

Figure 12.11 depicts a typical geocell slope protection system.

Figure 12.11 Basic Geocell Slope Protection System Components



Additional materials for quantity estimate are:

- Geocell panels or mats:
  - Are available in a variety of panel (mat) lengths and widths, and depths, however, only one standard cell size, 289 cm^2 (44.8 in^2) is currently acceptable. In most cases, a 100 mm (4 in) cell depth is sufficient. Cell depths of 150 mm (6 in) and 200 mm (8 in) are also available for use in special circumstances.
  - The panels collapse to form lightweight, compact bundles for shipping and handling. Panels expand to form, with connected adjacent panels, an expansive honeycomb over the protected area.
  - The number of staples required will vary depending on the ultimate load capacity and site conditions. Refer to Publication 72M, *Roadway Construction Standards* for more information. However, in most cases, staples evenly spaced 25 mm (1 in) part will suffice. Consequently, a 100 mm (4 in) cell depth will require at least 3 staples.
- Infill material:
  - Topsoil with various selected vegetation.
    - On vegetated slopes subject to mild or moderate surface erosion, cellular confinement with the geocell system confines and reinforces the vegetative root mat once it is established. The cells increase the vegetation's natural resistance to erosive forces and protect the root zone from loss of soil particles. The geocell walls, which confine the topsoil infill, form a series of check-dams extending throughout the protected slope. Each cell confines, protects and interlocks a predetermined depth of topsoil and the developing vegetative root mass. This prevents rill development from concentrated flow cutting into the soil. The cells redirect the flow continuously to the surface. Vegetated geocell systems are beneficial when aesthetics are important.
  - Aggregates (AASHTO No. 8, 67, 57 or PennDOT 2A).
    - On non-vegetated slopes, geocell systems with an aggregate infill provide effective slope protection by improving the erosion protection of granular materials such as AASHTO No. 8, 57, 67 and PennDOT 2A subbase material. The confinement of aggregates within cells permits the use of aggregates on steeper slopes than would otherwise be possible. The geocell configuration dissipates low hydraulic energy and minimizes down-slope migration of individual particles caused by gravity and hydraulic action.
  - Class C concrete with in accordance with Publication 408, *Specifications*.
    - Slope protection using concrete infill provides hard, durable protection of slopes by acting as a stay-in-place form on a slope. Geocell systems help prevent uncontrolled cracking of the concrete, reduce the chances of piping or undermining, and retain the flexibility and the ability of the construction to conform to minor subgrade movement. The quality, surface finish,

thickness of the concrete, and cell depth can be selected to meet site-specific design requirements.

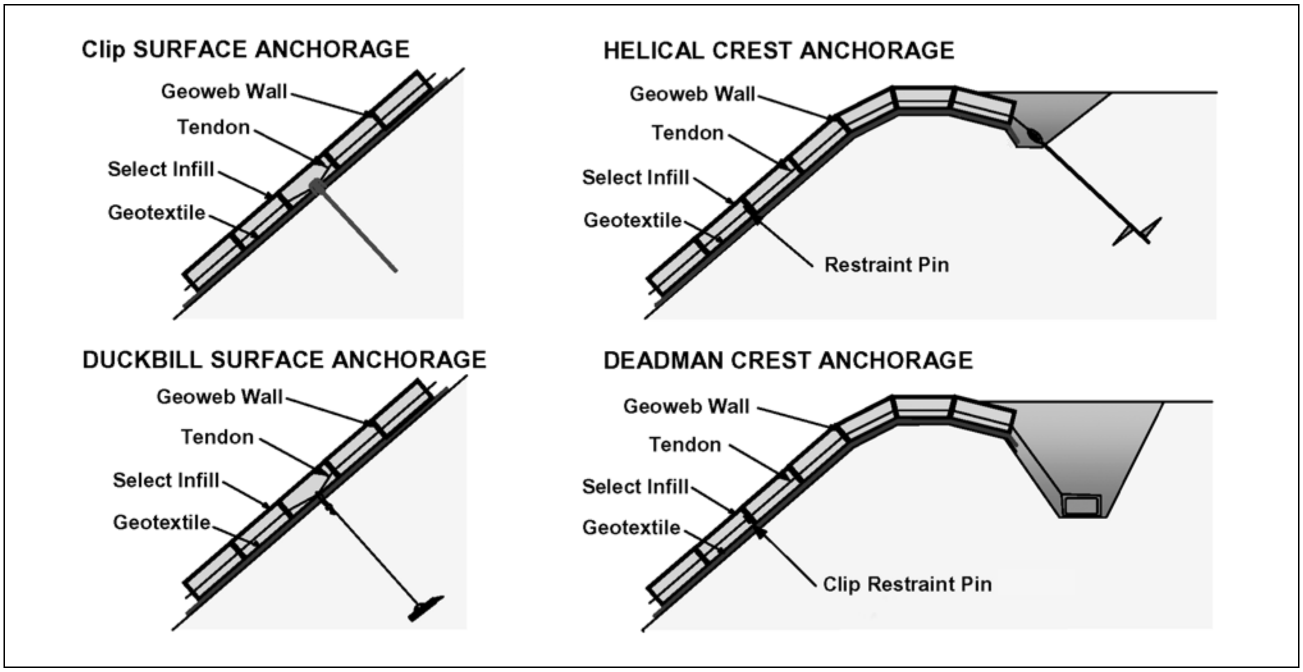
- Stake types and staking patterns:
  - Staking to a slope is the most common anchoring method used if there is no geotextile present and the soil has adequate strength to retain the stakes. Steel reinforcing bars (#4 rebar) bent into a "candy cane" shapes called J-hooks are the preferred type of stake. If the surface of the slope is covered with vegetation that will be mowed, then anchoring methods other than J-hooks, such as plastic clips, should be considered with the use of tendons. The determination of the staking pattern and stake length is explained in the design procedures. For additional stake types see Publication 72M, *Roadway Construction Standards*.
- Tendons and/or anchor assemblies:
  - To ensure the performance of geocell systems and satisfy design requirements, it may be necessary to incorporate tendons and anchor assemblies into the design.
  - Tendons serve to anchor geocell sections to the slope and are integrated into the geocell section through strategically spaced holes drilled through the cell walls running in the direction of expansion (up-down slope) of the sections. In addition to staking to the slope, the design will allow for securing the tendons by an anchoring system at the top (crest) of the slope/swale as indicated in Figure 12.12.
  - Standard tendons are high strength, plastic fibers, polyethylene coated (for corrosive environments or concrete infills) and uncoated, available in various ultimate tensile strengths. The design will determine the required strength, spacing and quantity of individual tendons within each geocell panel. Table 12.8 indicates an array of system specific tendons covering a range of tensile strengths to meet site specific design requirements.

Table 12.8 Typical Tendons

Material	**Construction**	**Tendon Diameter/Width**		**Minimum Break Strength**	
		mm	**in**	**kN**	**lb**
Polyester	Woven Strap (PE coated)	5	0.18	7.12	1600
	Woven Strap (Uncoated)	13	0.50	3.11	700
	Woven Strap (Uncoated)	19	0.75	6.70	1506
	Woven Strap (Uncoated)	19	0.75	9.30	2090
Kevlar	Woven Strap	10	0.375	8.90	2000
	Woven Strap	16	0.625	13.34	3000
Polypropylene	3 Strand Twisted Rope	6	0.25	4.40	990

  - The anchorage assembly for geocell systems consists of several surface anchors or crest anchorages placed with or without tendons (see Figure 12.12). Additional crest anchor systems such as an anchor trench and soil cover/embedment (i.e., direct burial) are detailed in Publication 72M, *Roadway Construction Standards* drawings. Design analysis (see Design Procedure) will determine the necessary anchorage details. Standard rebar in the configuration of a J-Pin or reinforcement bar with a clip-type head or end cap hold the geocell panels to the subgrade in surface anchorages. Special clips or restraints are available from the geocell manufacturers to connect tendons, where necessary, at specific load-transfer points at the cell walls for (crest) type anchorages. Tendons and surface stakes or earth anchors provide system anchoring that will resist sliding.
- Geotextile:
  - When the infill material is granular (aggregate), the geocell system should allow for a Class 2, Type B geotextile under layer to provide.
  - In-plane drainage of groundwater seepage from the slope subgrade.
  - Confinement and filtration of subgrade soil particles.
  - Reinforcement of root-mass with vegetated infills.
  - Tensile reinforcement of slope protection system.
- Slope erosion protection and soil stabilization:
  - When the infill material is topsoil to promote seed propagation, surface treatments such as erosion control blankets provide solutions to particular design requirements.

Figure 12.12 Typical Geocell Anchorage System



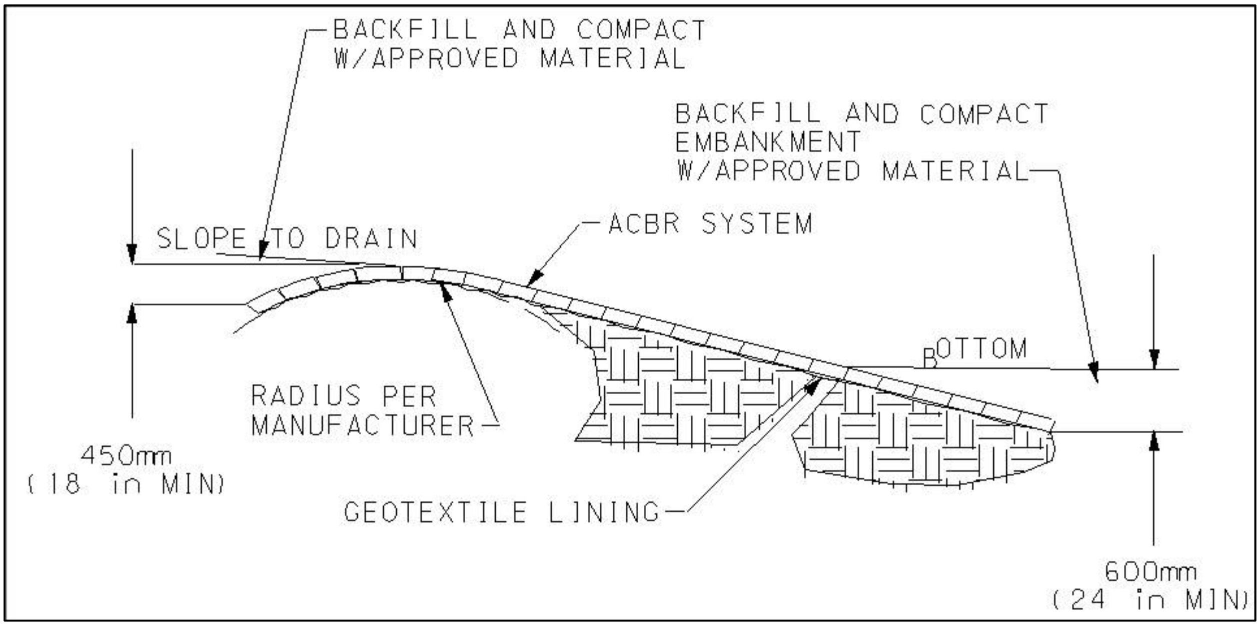
Include appropriate references, drawings, and notes on the plans including the following:

- Geocell cell and panel properties.
- Stapled or hog ring end and side connection details and load capacities.
- Anchor details.
- Crest anchor systems.
- Typical connection to existing structures.
- Drainage details through geocell sections.
- Geocell slope protection systems with restraint clips and tendons only.
- Geocell slope protection systems with tendons and clip anchors only.
- Geocell slope protection systems with restraint clips, tendons, and anchors.
- Curved and tapered section details.

E. Articulated Concrete Block Revetment System (ACBR). An ACBR system is a matrix of individual, permanently installed, concrete blocks placed together to form an erosion resistant overlay that meets static and hydraulic performance characteristics. ACBR systems can be used on subgrade that may expand or contract, and for slope protection to prevent embankment erosion, especially near waterways. ACBR systems consist of three-dimensional wet or dry cast preformed concrete units which are cable connected, interlocked or both. The assembled units form a continuous blanket or mattress over the protected surface. See Figure 12.13.

ACBR systems provide a flexible alternative to riprap, gabions, grouted rock, cast-in-place cement concrete slab slope walls, and pre-cast cement concrete block slope walls. Each revetment block system includes a design specific geotextile filter fabric, which allows infiltration and exfiltration to occur while providing particle retention of the soil subgrade. The blocks within the matrix are dense and durable and the matrix is flexible and porous due to the geometric configuration of each ACBR system.

Figure 12.13 Typical ACBR System



ACBR systems are a relatively recent development in erosion control and slope protection. Applications may include channel and swale lining, slope protection, channel protection at culvert inlets/outlets, temporary and emergency erosion control, etc. ACBR systems do have limitations to their flexibility and are relatively expensive. Their uses should be limited to severe erosion control requirements for permanent control where other alternatives are not as effective.

This section describes several proprietary systems that share common attributes and benefits such as: flexibility, rapid installation, support for vegetation, drainage of slope materials, facilitation of groundwater recharge, reduction of runoff velocities and volumes, enhancement of water quality, resistance to ice damage and freeze-thaw cycles, and mobility (for temporary uses). Unlike dumped rock or riprap, these systems are engineered or designed for a given flow and design shear. These systems are aesthetically pleasing and do not promote a habitat for rodents or a collection area for wind or water born debris.

The following section discusses design of ACBR systems and discusses several manufactured ACBR systems from different companies. The discussion covers the non-cabled ACBR systems first followed by the cabled ACBR systems. All of the systems discussed herein have been tested in accordance with the procedures outlined in *Minimizing Embankment Damage During Overtopping Flow*, (Clopper and Chen, 1988) and *Hydraulic Stability of Articulated Concrete Block Revetment Systems During Overtopping Flow* (Clopper, 1989). Table 12.9 summarizes the systems that are approved for PennDOT use by company, product name, and grouping (non-cabled or cabled).

Table 12.9 ACBR Systems

Company (Licensor)	Product	Non-Cabled	Cabled
Armortec	Armorflex		X
	Armorloc	X	
	A-Jacks	X	
International Erosion Control Systems, LLC	Cable Concrete		X

The design of a revetment system must result in a well-balanced and stable installation that functions as intended. The key design considerations for normal ACBR applications are the static or hydraulic capabilities of the system compared to the static or hydraulic requirements of the site, as well as drainage, separation, and anchorage. Static designs (e.g., slope applications) must then compare downslope force components of the weight of the system with any surcharge to the total resistive forces – interface friction, in-plane tensile anchorage and in-plane resistance of anchors with an appropriate factor of safety. Hydraulic designs (e.g., channels and swales) must compare the systems limiting shear stress and maximum velocity to the actual shear stress and velocity requirements with an appropriate factor of safety for the specific site. Each licensor of ACBR products in this section has conducted full-scale laboratory tests to determine their product's limiting shear stress and maximum velocity under hydraulic conditions.

Revetment design should always provide an engineering fabric or geotextile between the units and foundation soils. This helps to prevent soil loss and potential clogging of an aggregate drainage layer. Revetment designs also should include edge, toe/top entrenchment to prevent scour.

The design of an ACBR system for slope protection must demonstrate, by appropriate static or hydraulic analysis, that the system is stable and will serve as an effective erosion control countermeasure.

For highway slope protection and non-hydraulic conditions, contact the manufacturer to procure the static analysis procedure to determine the slope revetment stability and system requirements with a minimum factor of safety of 1.5.

For channel, swale, and outlet protection, as well as significant slope sheet flow, contact the manufacturer to obtain the system-specific hydraulic design procedure. Select an appropriate design event based on regulatory requirements, PennDOT design guidance, and sound engineering judgment.

The hydraulic design procedures for ACBR systems should follow HEC-23, *Bridge Scour and Stream Instability Countermeasures* (FHWA, 2001c). For use on PennDOT projects, ACBR products must meet testing and protocols requirements of *Minimizing Embankment Damage During Overtopping Flow* (Clopper and Chen, 1988) and *Hydraulic Stability of Articulated Concrete Block Revetment Systems During Overtopping Flow* (Clopper, 1989).

The procedure in HEC-23 determines the factor of safety by use of either design charts or equations. Typically, the revetment design should allow for a minimum factor of safety of 1.5 if the hydraulic conditions are known and variations in the installation can be determined. Assume a higher factor of safety for protection at junctures, outlets and bends due to the more complex shear stress calculations at those points.

HEC-23, *Bridge Scour and Stream Instability Countermeasures* (FHWA, 2001c) allows for consideration of forces due to projecting blocks, side slope correction factor (k), allowable and design shear stress and velocity; therefore, HEC-23 considers the hydraulic forces of lift (buoyant force and differential pressure across the block due to local accelerations), drag (shear stress/tractive force), and impact. This design procedure does not explicitly account for restrictive forces due to cable, anchoring devices or vegetation and is inherently conservative in terms of selection and design of an ACBR system.

Table 12.10 lists the design references for the company specific hydraulic design procedure and software for each ACBR system. The software indicated is not endorsed for use by PennDOT.

The installation of block revetment systems does not increase the stability of the underlying slope. Geotechnical engineering analyses must show that the protected slope is stable prior to consideration of revetment systems.

Design of pre-cast concrete block revetments should consider the following key factors:

- General revetment concept.
- Bank preparation.
- Mattress and block size.
- Slope and articulation.
- Edge treatment.
- Filter design.
- Surface treatment.

1. General Concept. Pre-cast block revetments must form continuous mattresses on the protected slope. The vertical and longitudinal extent of the mattress should be derived from design parameters and analysis. The design approach should emphasize edge treatment (toe of slope, top of slope and edges or flanks of revetment), block type, and filter design to suit site requirements (i.e., slope, soils, sheet flow velocity and duration, etc).

2. Slope/Bank Preparation. Slopes must be graded to a uniform slope. Large boulders, roots, and debris must be removed prior to final grading. Holes, soft areas, and large cavities must be filled, and the graded surface must be true to line and grade within 150 mm (6 in). Compaction of the bank surface must provide for a solid foundation for the mattress.

3. Mattress and Block Size. Identify the overall mattress size in accordance with the required longitudinal and vertical limits of the revetment system. In general, the revetment should be continuous for a distance greater than the required length and width so that erosive forces will not erode the slope material. Similarly, the revetment may form a continuous partial or full height (top of slope) mattress. Articulated block mattresses are assembled in sections. Consult manufacturer's literature when selecting an appropriate block size for given site conditions (i.e., slope, sheet flow, edge treatment, and surface treatment).

4. Slope and Articulation. Full-scale test results for certain systems are available. Table 12.11 indicates critical velocity and critical shear stress for a sampling of block sizes under bare or non-vegetated conditions, without anchors. Consult the manufacturer's design references (Table 12.10) for design values for other slopes and block sizes and threshold stabilities of velocity vs. slope and shear stress vs. slope under hydraulic conditions.

Table 12.10 ACBR System Design Procedures

Company	**Product**	**Design Procedure (Manual)**	**Software**
CONTECH (formerly Armortec Concrete Erosion Control Systems) 9025 Centre Pointe Drive West Chester, OH 45069 www.contech-cpi.com/Products/Erosion-Control.aspx (800) 338-1122	Armorflex	Designing Stable Channels with Armorflex Articulated Concrete Block Revetment Systems	Armorflex Stability Analysis for Open Channel Flow
	Armorloc	Appropriate Engineering Practice or Consult Company	Appropriate Design Software or Consult Company
	A-Jacks	A-Jacks Concrete Erosion Control System Streambank and Scour Applications	Consult Company
Royal Enterprises America (formerly International Erosion Control Systems, L.L.C.) 30622 Forest Boulevard P.O. Box 119 Stacy, MN 55079 www.royalenterprises.net (800) 817-3240	Cable Concrete	Cable Concrete Critical Shear Stress Values	Consult Company

Table 12.11 Actual Test Results

System	Slope (H:V)	Critical Velocity m/s (ft/s)		Critical Shear Stress kPa (psf)	
		m/s	ft/s	kPa	psf
ArmorLoc	Contact Manufacturer for specifications				
Cable Concrete (CC 45)	1.5:1	5.7	18.9	1.67	34.9
Armorflex (Class 305)	1:1	4.5	15	0.72	15

The minimum radius, R, for layout and articulation of the various systems is as shown in Table 12.12.

Table 12.12 Range of Articulation

System	cm	Minimum Radius	ft
ArmorLoc		N/A	
Cable Concrete		N/A	
Armorflex	60		2

5. Edge Treatment. The termination of pre-cast block revetments (the toe of slope, top of slope and possibly leading and trailing edges, also known as lateral edges, flanks or landward end of revetment) may require special treatment to prevent undermining. Toe treatments may include either a toe apron design (Figure 12.14) or a toe trench design to prevent scour in the vicinity of the slope toe.

Two suggested alternatives for termination treatments at the top, leading, and trailing edges are an at-grade termination or a termination trench, see Figure 12.14. Termination trenches are suited to environments subject to significant erosion (silty/sandy soils, and high velocities), or where failure of the revetment would result in significant economic loss. Termination trenches provide greater protection against failure from undermining and lateral erosion or stress than do at-grade terminations. Where upper bank erosion or lateral erosion is not problematic, at-grade terminations may be sufficient.

Specify earth anchors at regular intervals along the top of the revetment based on soil type, mat size, and the size of the anchors. Refer to the manufacturer's design procedures for suggested anchor spacing or determine spacing in accordance with recognized practice.

6. Filter. Specify a geotextile filter fabric on the slope to prevent slope material from leaching through the openings in the mattress structure. Although a fabric filter is desirable, graded filter material may be suitable with proper design and installation to prevent movement of the graded material through the protective mattress. The manufacturer's design procedures and HEC-11, *Design of Riprap Revetment* (FHWA, 1989) provide useful design guidance on filter design. Each of these systems uses a geotextile filter fabric that is unique to that particular system. These filter fabric geosynthetics will work on most highway project applications. Design of a geotextile is required only when the work calls for a concrete block revetment on a project with a large, navigable, tidal estuary that is subjected to wave action. These estuaries would be: Lake Erie, Delaware River, Allegheny River, Ohio River, and the Monongahela River.

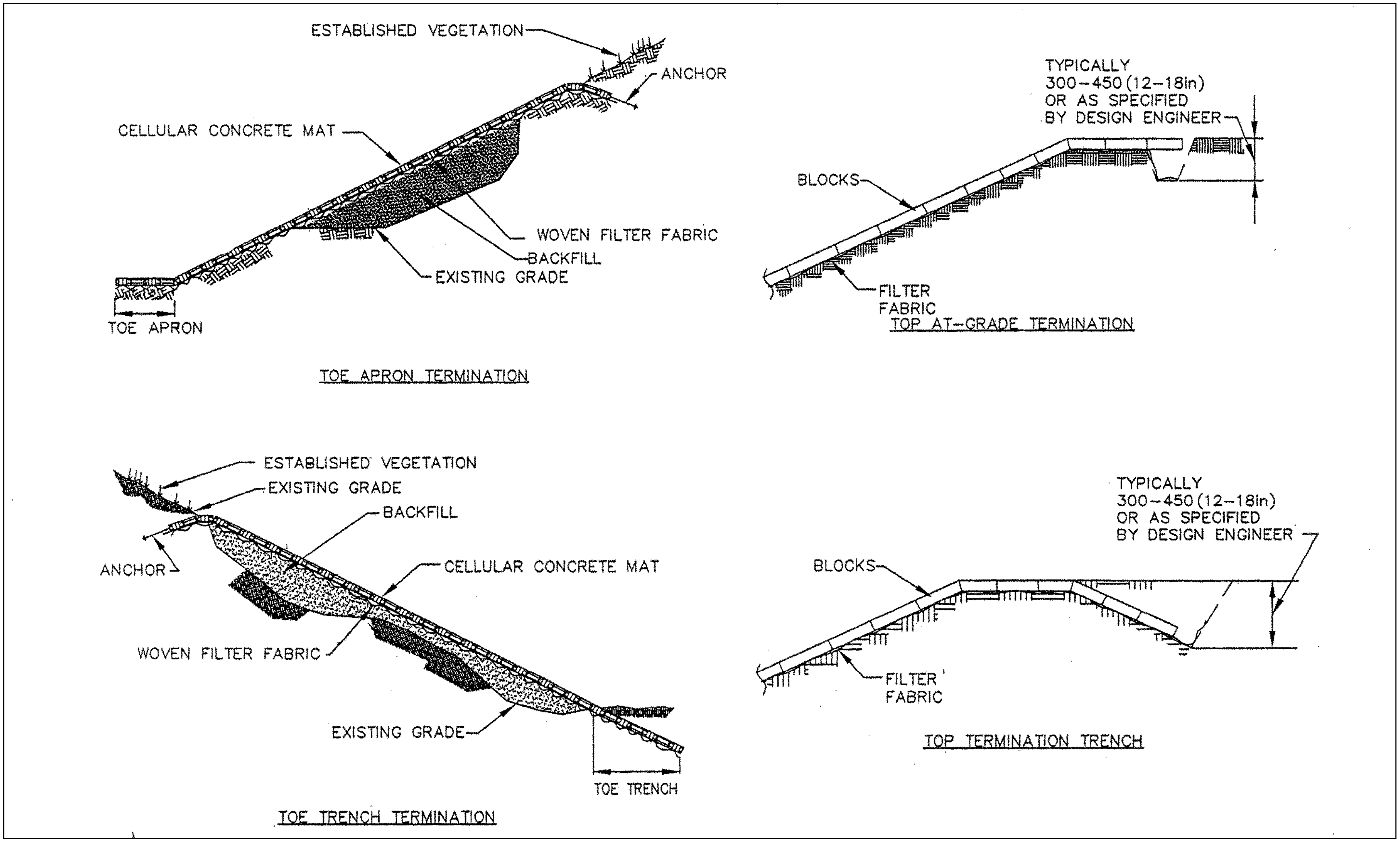
7. Surface Treatment. Specify backfilling of the spaces between and within individual blocks with either earth or aggregate. Soil backfill and seeding promotes the development of natural vegetation on the slope. Vegetation improves the structural stability of the embankment and enhances its appearance. Open-cell blocks are preferable for growth of vegetation. Use closed-cell blocks below the flowline or in areas where no vegetation will grow.

The following information and principles may provide additional guidance in the design and construction of a block revetment installation:

- Costs, aesthetics, and environmental benefits should be the basis for ACBR design.
- History of the ACBR system's performance and experience with comparable construction and sites should support the design process and methods.

Soil, watershed characteristics, and geotechnical characteristics of the site should support the design.

Figure 12.14 Termination Details for ACBR Systems



Proper planning and the appropriate funding for continued maintenance of the revetment should be considered in situations where the revetment may not entirely eliminate the erosion problem.

8. Non-Cabled ACBR Systems.

a. Description. The non-cabled systems consist of non-cabled blocks that are cast into interlocking shapes of various sizes that overlay a filter fabric and provide a positively connected matrix.

b. Attributes. Common attributes for non-cabled systems include:

- No metal to corrode, no fastening devices subject to abrasion or corrosion.
- No cables or additional anchoring.
- Ability to conform to changes in direction.
- Ability to go around structures without affecting system integrity.
- Fabrication as mats for machine installation.

c. Components and Function. Non-cabled systems are multi-component systems that consist of the following:

- Precast concrete blocks.
- Specific backfill or infill material.
- System specific filter fabric.

Non-cabled interlocking blocks are produced on concrete block machines. These blocks are available in various sizes, shapes and thicknesses. This type of ACBR system has excellent resistance to hydraulic shear and overtopping forces.

The blocks rest on a system specific filter fabric. The industry refers to the filter fabric as the carrier filter fabric when fabric is pre-attached to the blocks allowing the block and filter-fabric to be placed as integrated mats. The filter fabric provides:

- In-plane drainage of groundwater seepage from the slope subgrade.
- Confinement and filtration of subgrade soil particles.
- Reinforcement of root-mass with vegetated infills.
- Tensile reinforcement of slope protection system.

Once in place, non-cabled ACBR systems can accommodate several different infills, backfills, or surfaces. Aggregate in joints and voids, lends itself to a clean, unvegetated appearance. Topsoil in joints and voids, with or without Erosion Control Blankets (ECBs), provides an environment for establishing vegetation. Vegetation helps anchor the mat. The backfill material enhances the system's resistance to erosive and hydrostatic pressure, UV radiation and fabric degradation.

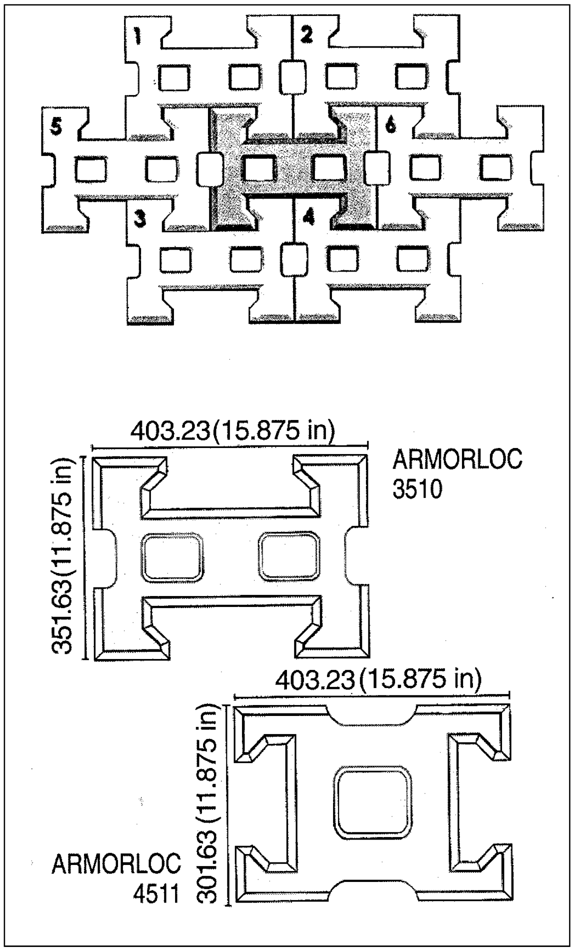
To ensure the integrity of the installation, the standard components must provide for some type of termination at the toe and top of slope, as well as at the edges. Figure 12.14 illustrates the use of the standard components in a variety of terminations.

9. Principal Proprietary Non-Cabled Systems.

a. ArmorLoc. The ArmorLoc system is a proprietary system that achieves an interlocking effect in which each block is keyed with four blocks in adjoining rows as well as abutting blocks on either side so that each individual unit is physically interlocked with six surrounding blocks to resist movement and uplift (see Figure 12.15). Trapped soil particles between block joints act as a dry grout, binding blocks into a continuous mattress.

The ArmorLoc block is available in two size and weight classifications: 40.323 cm (15.875 in) x 35.163 cm (11.875 in) x 10.160 cm (4.0 in) or 12.700 cm (5.25 in) with a weight of 13.6 - 15.8 kg/m^2 (30 - 35 lbs./sq. ft.) or 18.1 - 20.4 kg/m^2 (40 - 45 lbs./sq. ft.) and an open area of 25% or 20% of the grid.

Figure 12.15 Amorloc System Configuration



b. A-Jacks. The A-Jacks three-dimensional revetment system, Figure 12.16, is a proprietary system of interlocking concrete armor units for areas needing protection such as streams or banks. A-Jacks are assembled into a highly permeable, interlocking matrix by sliding one half into another to form a complete unit, refer to Figure 12.16.

Figure 12.16 A-Jacks

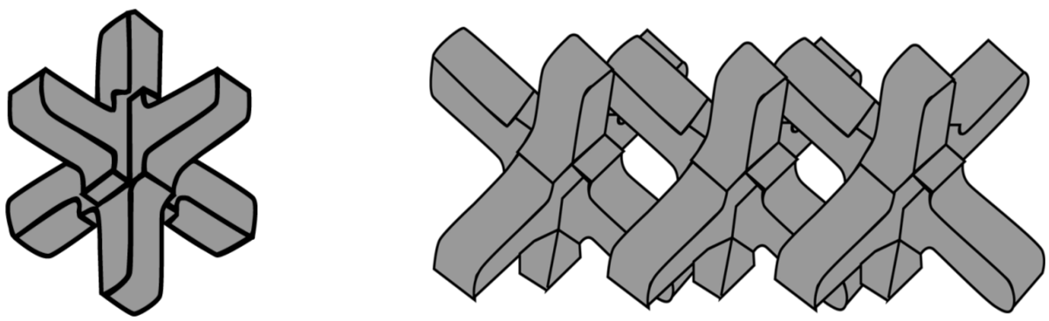
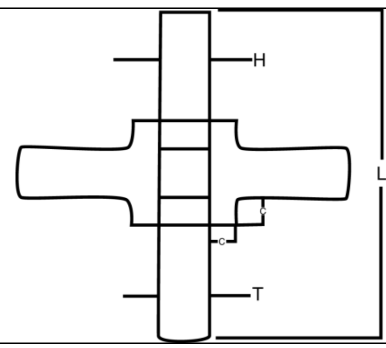


Table 12.13 is a summary of the sizes available. AJ-24 and AJ-36 are best used for streambank restoration. AJ-48, AJ-72, and AJ-96 are intended for energy dissipation. Refer to the manufacturer information for design specifications.

Table 12.13 Summary of A-Jacks Dimensions

A-Jacks	L (in)	T (in)	H (in)	C (in)	V1 (ft^3)	Wt (lbs)
AJ-24	24	3.68	3.68	1.84	0.56	78
AJ-36	36	5.52	5.52	2.76	1.89	265
AJ-48	48	7.36	7.36	3.68	4.49	629
AJ-72	72	11.04	11.04	5.52	15.14	2120
AJ-96	96	14.72	14.72	7.36	35.87	5022



10. Cabled ACBR Systems.

a. Description. These systems consist of interlocking or non-interlocking concrete blocks of various sizes with preformed, cast horizontal holes to permit installation of high-strength stainless steel cables through the matrix of blocks, binding them into a monolithic mat.

b. Attributes. Common attributes for cabled systems include:

- Availability in factory-assembled mats for machine installation.
- Fewer seams possible than with individual blocks.
- Ability to conform to existing ground contours.
- Temporary use and reuse from site to site.
- Permanent anchorage possible by connecting mat cables to anchors e.g. patented Helix, Ducksbill, or Royal anchors.

c. Components and Functions. Cabled systems consist of the following four basic components:

- Precast concrete blocks.
- Specific backfill or infill material.

- System specific filter fabric.
- High-strength stainless steel cable.

The basic components function similarly as in non-cabled systems. The cables facilitate placement and connection of mats, as well as, anchoring (as needed) but offer no hydraulic stability or structural value to the system.

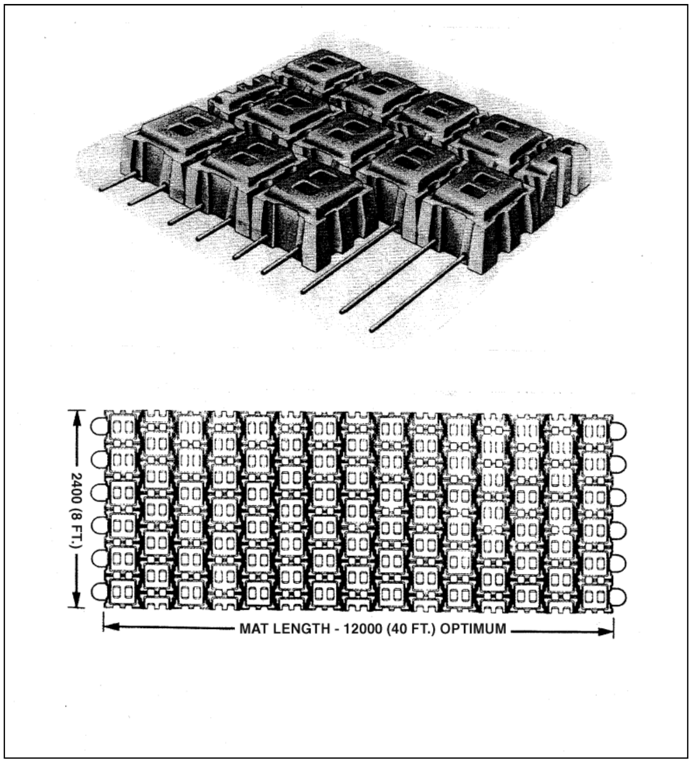
11. Principal Proprietary Cabled Systems.

a. ArmorFlex. The ArmorFlex system is a proprietary system of cable-bound individual blocks or (cellular) concrete block mats with specific hydraulic capabilities for various block classes and types (see Table 12.14). The blocks are open-cell or closed-cell blocks of normal weight aggregates or both, with an open area of not more than 12% or 20%, respectively. Parallel strands of cable extend through two ducts in each block in a manner that provides for longitudinal bending of the blocks within the system. Each row of blocks is laterally offset by one-half block width from the adjacent row so that any given block ties by cable to four other blocks (see Figure 12.17). The blocked interlocking surfaces prevent lateral displacement of the blocks in the event of cable damage or removal and allow for flexibility in all directions. When using concrete block mats, the system provides a minimum of 25° between any given row in the upward direction and a minimum 45° in the downward direction. The cables form lifting loops at either end of the mat. Cables and fittings are stainless steel. The ArmorFlex system may employ a permanent anchoring system by attachment to cables (e.g. in hanging mats on steep slopes without toe construction). The ArmorFlex blocks are useable without cables in which case they function as a non-cabled system.

Table 12.14 ArmorFlex Block System

Concrete Block Class	Open/ Closed Cell	Nominal Dimensions						Gross Area		Block Weight				Open Area %
		Length		Width		Height								
		cm	in	cm	in	cm	in	m^2	ft^2	kg	lbs	kg/in^2	lbs/ft^2	
30s	Open	33.0	13.0	29.5	11.6	12.1	4.75	0.09	0.98	14.0-16.3	31-36	156.2-180.6	32-37	20
50s	Open	33.0	13.0	29.5	11.6	15.2	6.00	0.09	0.98	20.4-23.5	45-52	219.7-258.7	45-53	20
40	Open	44.2	17.4	39.4	15.5	12.1	4.75	0.16	1.77	28.1-32.2	62-71	170.8-195.2	35-40	20
50	Open	44.2	17.4	39.4	15.5	15.2	6.00	0.16	1.77	36.7-42.6	81-94	224.5-258.7	46-53	20
60	Open	44.2	17.4	39.4	15.5	19.1	7.50	0.16	1.77	44.9-51.2	99-113	273.4-312.4	56-64	20
70	Open	44.2	17.4	39.4	15.5	22.9	9.00	0.16	1.77	54.4-62.5	120-138	332.0-380.8	68-78	20
40L	Open	44.2	17.4	59.9	23.6	12.1	4.75	0.23	2.58	40.8-48.0	90-106	170.8-200.1	35-41	20
50L	Open	44.2	17.4	59.9	23.6	15.2	6.00	0.23	2.58	52.6-60.7	116-134	219.7-253.8	45-52	20
60L	Open	44.2	17.4	59.9	23.6	19.1	7.50	0.23	2.58	65.3-76.2	144-168	273.4-317.3	56-65	20
70L	Open	44.2	17.4	59.9	23.6	22.9	9.00	0.23	2.58	78.4-91.1	173-201	327.1-380.8	67-78	20
45s	Closed	33.0	13.0	29.5	11.6	12.1	4.75	0.09	0.98	17.6-23.5	39-45	195.2-219.7	40-45	10
55s	Closed	33.0	13.0	29.5	11.6	15.2	6.00	0.09	0.98	24.0-27.6	53-61	263.6-302.7	54-62	10
45	Closed	44.2	17.4	39.4	15.5	12.1	4.75	0.16	1.77	35.3-40.3	78-89	209.9-244.1	43-50	10
55	Closed	44.2	17.4	39.4	15.5	15.2	6.00	0.16	1.77	42.6-48.9	94-108	258.7-297.8	53-61	10
75	Closed	44.2	17.4	39.4	15.5	19.1	7.50	0.16	1.77	54.4-62.5	120-138	332.0-380.8	68-78	10
85	Closed	44.2	17.4	39.4	15.5	22.9	9.00	0.16	1.77	65.7-75.7	145-167	400.0-478.4	82-98	10
45L	Closed	44.2	17.4	59.9	23.6	12.1	4.75	0.23	2.58	48.9-57.1	108-126	205.0-239.2	42-49	10
55L	Closed	44.2	17.4	59.9	23.6	15.2	6.00	0.23	2.58	63.0-73.9	139-163	263.6-307.5	54-63	10
75L	Closed	44.2	17.4	59.9	23.6	19.1	7.50	0.23	2.58	78.4-91.1	173-201	327.1-380.8	67-78	10
85L	Closed	44.2	17.4	59.9	23.6	22.9	9.00	0.23	2.58	94.8-110.2	209-243	395.4-458.9	81-94	10

Figure 12.17 Armorflex Block Configuration



b. Cable Concrete. The Cable Concrete system is a proprietary system that consists of non-interlocking pyramidal shaped concrete blocks interwoven with stainless steel cable. Figure 12.18 illustrates the original closed-cell block sizes. The units are also available in three other original and three oversized block sizes. The cable runs both lengthwise and widthwise, providing loops on all sides for clamping to adjacent mats and possible anchoring. The manufacturer attaches the underlying geotextile fabric to the mat at the plant. The pyramidal block shape allows for articulation ranging from 20° to 60°, depending upon block size (see Table 12.15).

Figure 12.18 Cable Concrete Configuration

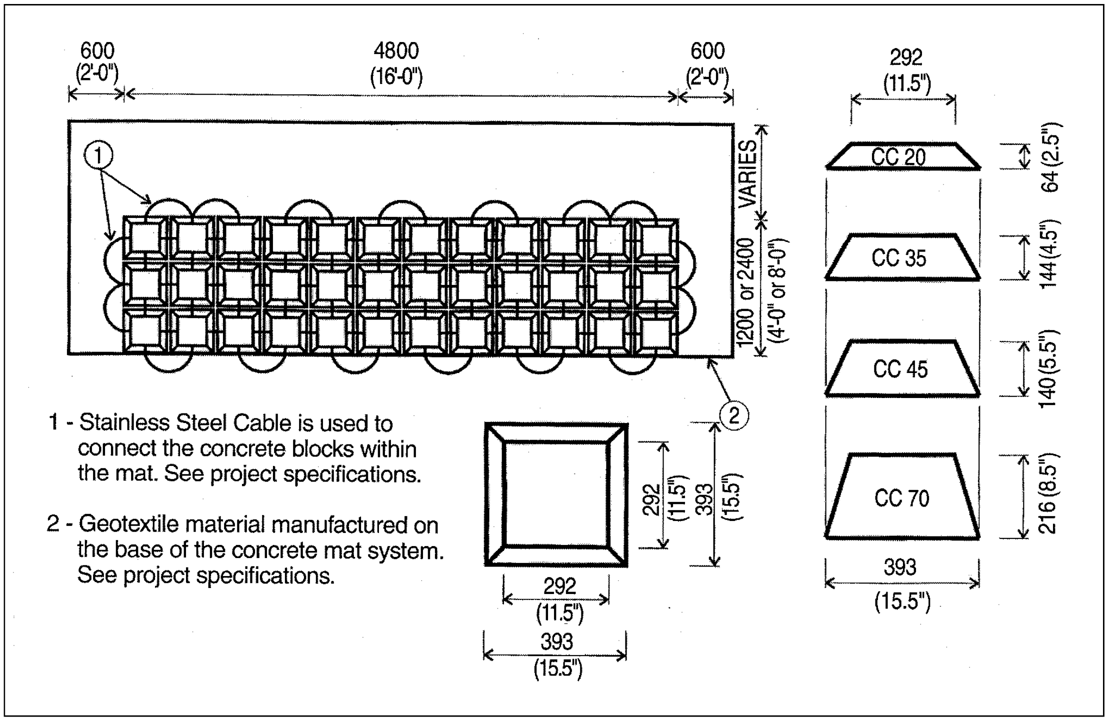


Table 12.15 Cable Concrete Block Specifications Original Block – Closed Cell

	Model	**CC 20**				**CC 35**				**CC 45**				**CC 70**			
Mat	**Unit Weight**	**kg/m^2**		**lbs/ft^2**		**kg/m^2**		**lbs/ft^2**		**kg/m^2**		**lbs/ft^2**		**kg/m^2**		**lbs/ft^2**	
		112.2		23		200.1		41		244.1		50		375.9		77	
	Area	m^2	ft^2	m^2	ft^2	m^2	ft^2	m^2	ft^2	m^2	ft^2	m^2	ft^2	m^2	ft^2	m^2	ft^2
		5.9	64	11.8	128	5.9	64	11.8	128	5.9	64	11.8	128	5.9	64	11.8	128
	Weight	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb
		615.6	1355	1319.9	2910	1183.8	2620	2458.4	5420	1451.4	3200	2902.9	6400	2245.2	4950	4490.5	9900
	Blocks/Mat	36		72		36		72		36		72		36		72	
Blocks	**Spacing @ Base**	mm		in		mm		in		mm		in		mm		in	
		13		0.5		13		0.5		13		0.5		13		0.5	
	Spacing @ Top	114		4.5		114		4.5		114		4.5		114		4.5	
	Weight	kg		lb		kg		lb		kg		lb		kg		lb	
		18.1		40		33.1		73		40.3		89		62.1		137	
	Height	mm		in		mm		in		mm		in		mm		in	
		64		2.5		114		4.5		140		5.5		216		8.5	
Cable		Length		Width		Length		Width		Length		Width		Length		Width	
	Diameter	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in
		3	1/8	3	1/8	4	5/32	4	5/32	4	5/32	4	5/32	5	3/16	4	5/32
	Construction	1 x 19		1 x 19		1 x 19		1 x 19		1 x 19		1 x 19		1 x 19		1 x 19	
		kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb
	Breaking Strength	952.5	2100	952.5	2100	1496.8	3300	1496.8	3300	1496.8	3300	1496.8	3300	2131.8	4700	1496.8	3300
Open Area		8.2%															

The following information should be included in the details or General E&SPC Construction Notes on the plans:

- Prepare the area by clearing and grubbing, excavating, removing unstable material, backfilling, placing, and compacting embankment, or other means necessary prior to placing geotextile and ACBR. The graded surface must be true to line and grade within 150 mm (6 in) or per manufacturer's specifications.
- Place geotextile in accordance with specifications in Publication 408, *Specifications*.
- The ACBR will be constructed/installed as specified in the plans. After the ACBR is placed, selected infill or backfill will be placed over the blocks to allow for vegetation. For unvegetated surfaces, the blocks can be left in place with no backfill.
- Refer to seeding specifications in Publication 408, *Specifications*.
- Backfill and compact (with approved material) each end of the ACBR for stabilization. Top fill: 450 mm (18 in) minimum. Bottom fill: 600 mm (24 in) minimum. AASHTO No. 57 crushed stone or equivalent can be used as an approved backfill material to act as a drainage medium.
- Termination of the ACBR will be constructed in accordance with manufacturer's suggestions.

The plans should clearly indicate or note:

- Termination details at toe, edges or flanks and top of slope as required and final grades of slope.
- Details for optional anchors at the top and edges or flanks of the protection as required.
- Filter fabric and/or graded filter on the prepared subgrade.
- Detail of individual block units or individual mats on the slope side by side.
- As applicable, connection details for attachment of adjacent mats to one another and to anchors.
- The backfill details over the mats (and into the open cells or spaces between cells) and into the anchor trenches.
- Seeding and fertilizer limits.

F. Gabions. Gabions are rock-filled, multi-celled, rectangular, open mesh wire baskets used for the construction of erosion control protection structures. Gabions generally are available in two different types based on shape: mattress or blocks. Gabions are used to prevent erosion and scour from high velocity flows in erosion prone areas. Gabions provide both permanent and temporary solutions for erosion problems.

There are several applications for gabions. Their structural versatility allows them to be used as slope walls, channel lining, and channel deflectors to prevent scour and erosion. For additional guidance on the application of gabions refer to HEC-11, *Design of Riprap Revetment* (FHWA, 1989); HEC-15, *Design of Roadside Channels with Flexible Linings* (FHWA, 2005a); HEC-23; *Bridge Scour and Stream Instability Countermeasures* (FHWA, 2001c), and Design Manual Part 4.

In mattress designs, the individual wire mesh units are laid end-to-end and side-to-side to form a mattress layer in a channel or on a slope. This type of gabion generally has a depth dimension that is much smaller than the width or length.

Block designs are typically rectangular in shape where the depth and width are approximately the same. Blocks are installed by stacking the individual blocks on top of each other in a stepped fashion.

Gabions must conform to the details, as shown in Publication 72M, *Roadway Construction Standards*, and may be considered by the designer for the following categories:

- Slope Walls. Slope walls can be constructed using mattresses, i.e., the 225 mm (9 in) thick wire baskets, or Blocks in 300 mm (12 in) or 450 mm (18 in) thickness. The thickness is usually dictated by the size of coarse aggregate available for backfilling the wire baskets. Two overlapping layers of coarse aggregate are the minimum suggested to keep any water from having a direct path to the soil. Maximum permissible velocities for various thicknesses of mattresses and blocks are specified in Table 12.16.

Table 12.16 Maximum Permissible Velocities for Mattress and Block Gabions

Type	Thickness		Permissible Velocity	
	mm	**in**	**m/s**	**ft/s**
Mattress	<152	<6	1.8	6.0
	<254	<10	3.6	12.0
	<305	<12	4.5	15.0
	<457	<18	5.4	18.0
Block	>457	>18	6.7	22.0

Reference: *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

Slope walls, adjacent to flowing water, must be protected against scour by either an apron or a toe wall of gabions. The apron should be approximately two times as wide (W_G as indicated on Standard Drawing RC-43M) as the anticipated depth of scour. If the channel is sharply curved, toe walls are preferred over aprons and the toe wall height (H_G as indicated on Standard Drawing RC-43M) should be at least equal to the anticipated depth of scour.

- Channel Lining. The lining thickness required for gabions is dictated by the maximum permissible velocities indicated in Table 12.16. On Standard Drawing RC-43M an illustration of gabions as channel linings is shown.

Limitations to the use of gabions include material costs and design requirements. Also the designer should be aware of other considerations which might include impacts to stream dynamics and impacts on stream and wildlife habitat.

Temporary channels are to be designed to convey the peak discharge from the 2-year frequency storm event. In Special Protection Watersheds, the 5-year design storm should be used for temporary channels. All permanent channels are to be designed to convey the 10-year storm peak discharge.

The standard gabion sizes presented in Publication 72M, *Roadway Construction Standards,* represent sizes available in quantity from approved manufacturers. Additional sizes may be available on a special order basis only. When gabions are used for other purposes, refer to the publications listed previously in this section.

Construction and maintenance of gabions should be considered when gabions are placed on a 1V:1.5H (1.5H:1V) side slope or steeper, drive hardwood stakes through the gabions, along the top edge, to anchor the installation. Embed stakes 450 mm (18 in) minimum below gabion bottom. An apron or toe wall is required where the slope wall is installed adjacent to water. Make the apron approximately two times as wide as the anticipated depth of scour and the toe wall height at least equal to the anticipated depth of scour. Channel lining installation can be a sediment producing activity. Maintain E&SPC BMP during channel work in flowing waterways. Temporary diversions or piping should be employed to prevent waterway sedimentation. Check wire of baskets for corrosion and wear. When gabions are used as permanent stabilization, baskets should be inspected periodically for damage or deterioration. In addition, when gabions are used in a submerged environment, consider using corrosion resistant metal baskets to improve durability.

12.5 GENERAL E&SPC BMPS

General BMPs are utilized during earth moving activities to prevent erosion or the transport of sediment off the project site.

A. Rock Construction Entrance. A rock construction entrance is a stabilized pad of aggregate placed at every entrance and exit point of a construction site. Rock construction entrances are used to reduce offsite transport of soil by removing mud and sediment from the wheels of construction vehicles prior to exiting the construction site. A typical rock construction entrance should be designed as shown on Standard Drawing RC-77M. The minimum travel length of the entrance is 15 m (50 ft). This is the length of track over which the truck must drive. The minimum width of the entrance is 6 m (20 ft). In some cases the designer may want to pave the area adjacent to the travelway. Examples of where this may be desirable are in high traffic areas where spilled aggregate on the paved roadway surface may pose a safety hazard, or if pavement integrity where the rock construction entrance is located is an issue. In these cases, the minimum travel length of the entrance is 30 m (100 ft), with the first 15 m (50 ft) being paved.

Maintenance of rock construction entrances should be considered during construction. Remove sediment deposited on paved roadways and return it to the construction site. Do not wash the roadway or sweep the deposits into roadway ditches, sewers, culverts, or other channels. Repair damaged wash racks as necessary to maintain their effectiveness. Rock construction entrances should be inspected daily. Rock construction entrance thickness should be constantly maintained to the specified dimensions.

B. Rock Filter Outlet. Rock filter outlets can be defined as a temporary barrier of coarse aggregate and silt barrier fence used to remove sediment. Rock filter outlets are used to replace areas of silt barrier fence that have been undercut or overtopped. Typical rock filter outlet placement is shown on Standard Drawing RC-70M.

Rock filter outlets should be maintained during construction by removing accumulated sediment it reaches one-third the height of the rock filter. Rock filter outlets should be inspected daily and after each rainfall event. Damaged outlets or loss of aggregate should be repaired immediately to the required dimensions.

C. Compost Filter Sock. A compost filter sock can be defined as a temporary barrier of organic compost in a water permeable mesh used to remove sediment from sheet flow runoff. Compost filter socks are constructed below a disturbed area to protect receiving surface water from runoff from the disturbed area. Compost filter socks range in diameter from 300 mm (12 in) to 600 mm (24 in). Typical compost filter sock placement is shown on Standard Drawing RC-70M.

Compost filter socks should be considered for use in the following areas:

- At the toe of fill slopes and along the downslope perimeter of disturbed areas where runoff continues to sheet flow away from the area.
- Around the perimeter of all temporary soil stockpiles maintained on the project site.
- Where rock or rocky soils inhibit anchoring of silt barrier fence.
- Around the perimeter of wetlands, streams or other sensitive areas.

There is no formal design procedure for compost filter socks beyond placement in the appropriate locations. Place compost filter socks downslope of all disturbances, in stabilized areas, and parallel to contours so that the filter socks are on level grade and so that the sock makes continuous contact with the underlying soil. Filter socks should not be placed across concentrated flow (e.g., channel swales, erosion gullies, across pipe outfalls, or as inlet protection).

Extend both ends of the compost filter sock at least 2.4 m (8 ft) up slope at 45 degrees to the main alignment to allow for pooling of water. Ensure a minimum of 300 mm (12 in) to either side of the area to be protected. The filter sock should also be placed at least 2.4 m (8 ft) from the toe of slope if possible. Limit compost filter sock use to areas where the slope is milder than 1V:2H (2H:1V). The total length of slope behind the filter sock should not exceed the values in Table 12.17. Slope length is the distance from the filter sock to the drainage divide or nearest upslope channel. Filter socks cannot be placed in multiple rows to increase the allowable slope length. Additional compost filter sock specifications and details (e.g., anchor post spacing) are provided in Publication 408, *Specifications*, and in Publication 72M, *Roadway Construction Standards*, respectively.

Maintenance of compost filter socks during construction should be considered. Accumulated sediment should be removed as necessary or when sediment accumulation reaches one-half the height of the exposed compost filter sock. Compost filter socks should be inspected weekly and after each rainfall event. Any section of compost filter sock that has been undermined or washed out should be immediately replaced.

Table 12.17 Maximum Slope Length for Compost Filter Socks

	Maximum Slope Length					
Slope Percent	**300 mm (12") Diameter**		**450 mm (18") Diameter**		**600 mm (24") Diameter**	
	m	**ft**	**m**	**ft**	**m**	**ft**
2 (or less)	225	750	300	1000	400	1300
5	150	500	165	550	200	650
10	75	250	90	300	120	400
15	50	170	60	200	100	325
20	38	125	42	140	80	260
25	30	100	33	110	60	200
30	23	75	27	90	40	130
35	23	75	24	80	35	115
40	23	75	24	80	30	100
45	15	50	18	60	24	80
50	15	50	17	55	20	65

Reference: Filtrexx SiltSoxx

D. Compost Filter Berm. A compost filter berm can be defined as a temporary barrier of organic compost used to remove sediment from sheet flow runoff. Compost filter berms are constructed below a disturbed area to protect receiving surface water from runoff from the disturbed area. Compost filter berms are trapezoidal shaped berms that are 1200 mm (48 in) wide and 600 mm (24 in) high. A typical compost filter berm placement is shown on Standard Drawing RC-70M.

Compost filter berms should be considered for use in the following areas:

- At the toe of fill slopes and along the downslope perimeter of disturbed areas where runoff continues to sheet flow away from the area.
- Around the perimeter of all temporary soil stockpiles maintained on the project site.
- Where rock or rocky soils inhibit anchoring of silt barrier fence.
- Around the perimeter of wetlands, streams or other sensitive areas.
- Where rock or uneven ground prevents the use of compost filter socks due to the inability to provide continuous contact with the underlying soil.

There is no formal design procedure for compost filter berms beyond placement in the appropriate locations. Place compost filter berms downslope of all disturbances, in stabilized areas, and parallel to contours so that the filter berms are on level grade. Place compost filter berms a minimum of 2.4 m (8 ft) from toe of fill slopes, where possible. Filter berms should not be placed across concentrated flow (e.g., channel swales, erosion gullies, across pipe outfalls, or as inlet protection).

Extend both ends of the compost filter upslope to the main alignment to allow for pooling of water. Limit compost filter berm use to areas where the slope is milder than 1V:2H (2H:1V). The total length of slope behind the barrier should correspond to the allowable slope lengths for a 750 mm (30 in) silt barrier fence (see Table 12.20). Slope length is the distance from the filter berm to the drainage divide or nearest upslope channel. Filter berms cannot be placed in multiple rows to increase the allowable slope length. Additional compost filter berm specifications are provided in Publication 408, *Specifications*.

Maintenance of compost filter berms during construction should be considered. Accumulated sediment should be removed as necessary or when sediment accumulation reaches one-third the height of the exposed berm. Compost filter berms should be inspected weekly and after each rainfall event. Any section of compost filter berms that has been undermined or overtopped should be immediately replaced.

E. Silt Barrier Fence. Silt barrier fence can be defined as a temporary barrier of entrenched geotextile (filter fabric) stretched across and attached to supporting posts. Silt barrier fence is used to remove sediment from sheet flow runoff. Silt barrier fences are constructed below a disturbed area to protect receiving surface water from runoff from the disturbed area.

Silt barrier fence should be considered for use in the following areas:

- At the toe of fill slopes and along the downslope perimeter of disturbed areas where runoff continues to sheet flow away from the area.
- Around the perimeter of wetlands, streams or other sensitive areas.
- Around the perimeter of all temporary soil stockpiles maintained on the project site.

Silt barrier fence is NOT appropriate for use in the following areas or manners:

- Concentrated flow (e.g., channel swales, erosion gullies, across pipe outfalls, or as inlet protection, etc.).
- Where rock or rocky soils prevent anchoring of the fence or proper installation of the fence posts.
- In multiple rows to increase slope length.
- On fills or in extremely loose soils (e.g., sandy loam).
- In wooded areas, where tree roots prevent proper anchoring of the fence.

There is no formal design procedure for silt barrier fence beyond placement in the appropriate locations. Place silt barrier fence downslope of all disturbances, in stabilized areas, and parallel to contours so that the fence is on level grade. Extend both ends of each fence section at least 2.4 m (8 ft) up slope at 45 degrees to the main fence alignment to allow for pooling of water. Limit silt barrier fence use to areas where the slope is milder than 1V:2H (2H:1V). The total length of slope behind the barrier should not exceed the values shown in Table 12.18. Slope length is the distance from the fence to the drainage divide or nearest upslope channel. Silt barrier fence post spacing and geotextile classification criteria is provided in Table 12.19 and in Publication 72M, *Roadway Construction Standards*.

Maintenance of silt barrier fences during construction should be performed to ensure continued function. Accumulated sediment should be removed as necessary or when sediment has accumulated to one-half above the ground height of the fence. Silt barrier fence should be inspected weekly and after each rainfall event. Any section of silt barrier fence that has been undermined or overtopped should be immediately replaced with a rock filter outlet.

Additional silt barrier fence specifications and details are provided in Publication 408, *Specifications*.

1. Silt barrier fence, 450 mm (18 in) height. This type of silt barrier fence is the minimum height of silt barrier fence used by PennDOT. On Standard Drawing RC-70M, a typical silt barrier fence, 450 mm (18 in) height detail is shown.

2. Silt barrier fence, 750 mm (30 in) height. This type of silt barrier fence is the maximum height of silt barrier fence used by PennDOT. On Standard Drawing RC-70M, a typical silt barrier fence, 750 mm (30 in) height detail is shown.

Table 12.18 Silt Barrier Fence Slope Length

Slope Percent	Maximum Slope Length			
	Silt Barrier Fence 450 mm (18 in Height)		Silt Barrier Fence 750 mm (30 in Height)	
	m	ft	m	ft
2 (or less)	45	150	150	500
5	30	100	75	250
10	15	50	45	150
15	10	35	30	100
20	8	25	20	70
25	6	20	17	55
30	4.5	15	14	45
35	4.5	15	12	40
40	4.5	15	11	35
45	3	10	9	30
50	3	10	8	25

Reference: *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

Table 12.19 Silt Barrier Fence Post Spacing and Geotextile Requirements

Silt Barrier Fence, Height	Type of Class 3 Geotextile Material	Nominal Geotextile Height	Post Spacing Without Mesh Support	Max. Post Spacing With Mesh Support
450 mm (18 in)	3A	750 mm (18 in)	2.4 m (8 ft)	NA
750 mm (30 in)	3A	1050 mm (30 in)	NA	2.4 m (8 ft)
450 mm (18 in)	3B	750 mm (18 in)	1.2 m (4 ft)	NA
750 mm (30 in)	3B	1050 mm (30 in)	NA	1.2 m (4 ft)

Reference: Publication 72M, *Roadway Construction Standards*, RC-70M.

F. Heavy Duty Silt Barrier Fence. Heavy duty silt barrier fence is a temporary barrier of entrenched geotextile backed with wire fabric (i.e., chain link) fence. Both the wire fabric and geotextile are stretched across and attached to supporting posts. Heavy duty silt barrier fence may be used to control runoff from small, disturbed areas where the maximum slope lengths for silt barrier fence cannot be met and sufficient room for construction of a sediment trap does not exist.

Heavy duty silt barrier fence should be considered for use in the following areas or manners:

- Where the maximum slope lengths for silt barrier fence are exceeded. The maximum slope length above heavy duty silt barrier fence should not exceed that shown in Table 12.20. Slope length is the distance from the fence to the drainage divide or nearest upslope channel.
- Where access is possible by construction equipment required to install and remove the chain link fencing, including a posthole drill.
- Around the perimeter of all temporary soil stockpiles maintained on the project site.

There is no formal design procedure for heavy duty silt barrier fence beyond placement in the appropriate locations. Place heavy duty silt barrier fence downslope of all disturbances, in stabilized areas, and parallel to contours so that the fence is on level grade. It should not be placed across concentrated flow (e.g., channel swales, erosion gullies, across pipe outfalls, or as inlet protection). Where rock or rocky soils prevent anchoring of the fence or the proper installation of the fence posts, another BMP strategy should be examined.

Extend both ends of each fence section at least 2.4 m (8 ft) up slope at 45 degrees to the main fence alignment to allow for pooling of water. Limit heavy duty silt barrier fence use to areas where the slope is milder than 1V:2H (2H:1V). The total length of slope behind the barrier should not exceed the values shown in Table 12.20. Slope length is the distance from the fence to the drainage divide or nearest upslope channel. Filter berms cannot be placed in multiple rows to increase the allowable slope length. On Standard Drawing RC-70M a typical heavy duty silt barrier fence detail is shown.

Maintenance of heavy duty silt barrier fences during construction should be performed to ensure continued function. Accumulated sediment should be removed as necessary or when sediment has accumulated to one-half above the ground height of the fence. Heavy duty silt barrier fence should be inspected weekly and after each rainfall event. Any section of heavy duty silt barrier fence that has been undermined or overtopped should be immediately replaced with a rock filter outlet. Adhere to the manufacturer's suggestions relative to required geotextile placement during weathering.

Additional heavy duty silt barrier fence specifications and details are provided in Publication 408, *Specifications,* and on Standard Drawing RC-70M.

Table 12.20 Heavy Duty Silt Fence Slope Length

Slope Percent	**Maximum Slope Length**	
	m	**ft**
2 (or less)	300	1,000
5	165	550
10	100	325
15	65	215
20	50	175
25	40	135
30	30	100
35	25	85
40	22	75
45	18	60
50	15	50

Reference: *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

G. Vegetative Filter Strip for E&SPC. A vegetative filter strip is a well-established perennial grassy area located below a disturbed area that can be used to remove sediment from runoff prior to it reaching receiving waters. The purpose of a vegetative filter strip is to provide an area that slows sediment-laden runoff allowing the sediment to filter out, prior to reaching the receiving waters.

Vegetative filter strips are effective if runoff is in the form of sheet flow and if the vegetative cover is established prior to receiving runoff. It is best to have an area of existing, well-established perennial grass. It should be noted that vegetative filter strips take a considerable amount of space. Right-of-way availability should be considered prior to selection and design of this BMP. Use of vegetative filter strips on adjacent properties is not acceptable.

Refer to Table 12.21 for the slope length requirements and maximum length of flow to be treated by the strip. Vegetative filter strips function best at slopes less than 5%. Using Equation 12.1, define the minimum width of a vegetative filter strip. The minimum acceptable width is 15 m (50 ft) as shown in Figure 12.19.

(*Equation 12.1*)

Metric:

$$W_{(min)} = 0.61S + 7.5$$

U.S. Customary:

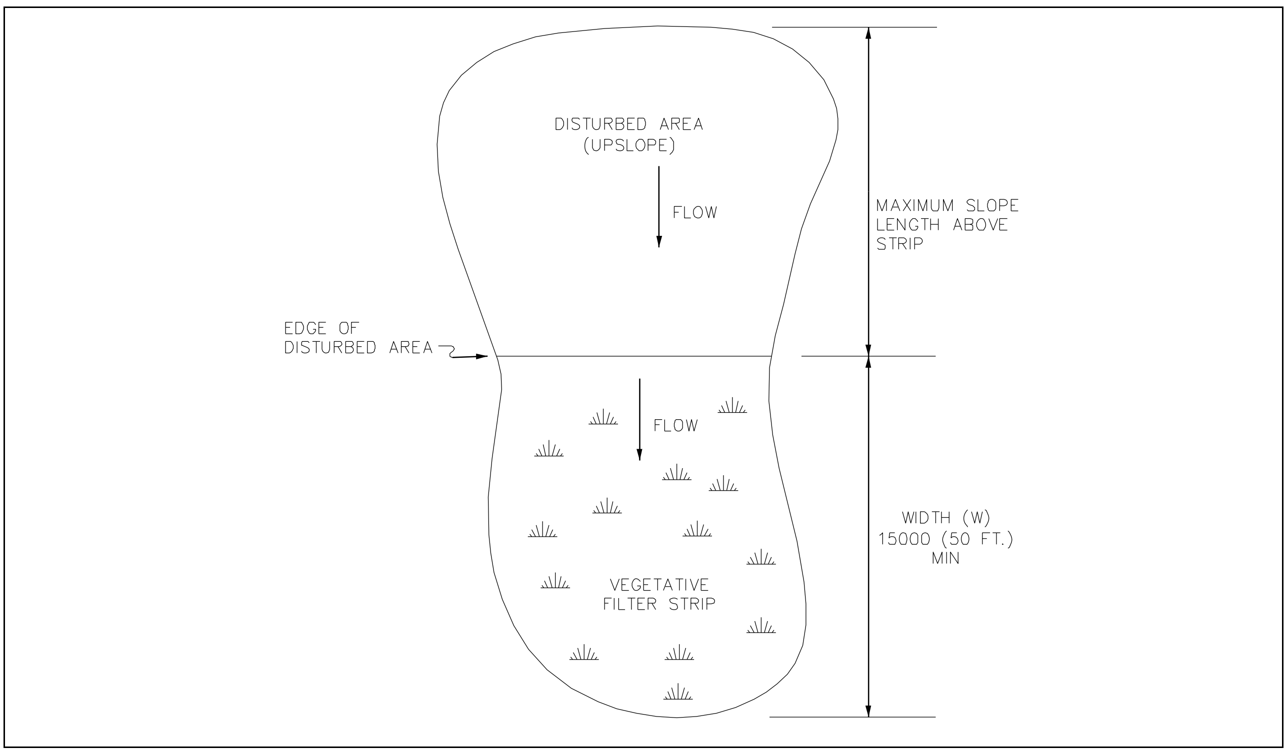
$$W_{(min)} = 2S + 25$$

Where: W_{min} = Minimum Filter Strip Width, m (ft)
S = Average Slope Percent

Table 12.21 Maximum Flow Length For Vegetative Filter Strip Slope

Slope Percent	**Maximum Slope Length Above Strip**	
	m	**ft**
2 (or less)	45	150
5	30	100
10	15	50
15	10	35
20	7.5	25
25	6	20
30	4.5	15
35	4.5	15
40	4.5	15
45	3	10
50	3	10

Figure 12.19 Vegetative Filter Strip



Accumulated sediment on vegetated filter strips should be removed as necessary. If the vegetated filter strip width is reduced by more than half of its original width due to accumulated sediment, an alternative, such as a compost filter sock or silt barrier fencing, should be installed immediately.

Refer to Publication 13M, Design Manual, Part 2, *Highway Design*, Section 13.6 and the *Pennsylvania Stormwater Best Management Practices Manual* (PA DEP, 2006), for design guidance on permanent vegetative filter strips. The filter strip design in this section of the manual is for erosion and sediment pollution control only.

H. Pumped Water Filter Bag (also known as a Sediment Filter Bag). Pumped Water Filter Bags (PWFBs) are non-woven, geotextile fabric bags with double stitched "J" type seams and a sewn-in spout. The maximum pore size in a PWFB is 150 microns. Refer to Publication 408, *Specifications,* and on Standard Drawing RC-75M for a detail and general notes associated with this BMP.

PWFBs can be used in a variety of construction areas where sediment-laden water is present and dewatering is needed. In general, they are used when water is pumped from excavation holes associated with bridge piers and abutments. They can also be used to dewater trenches and to filter water pumped from sediment traps or sediment basins when dewatering sediment storage zones of these facilities.

A design for this BMP is not required; however, the contractor must match the PWFB size to the particular pump such that the pumping rate to the bag is no greater than 2,840 L/min (750 gal/min) or ½ the maximum specified by the manufacturer, whichever is less. This requirement is due to the assumption that water will only discharge through to top half of the bag. A general note for this is located on Standard Drawing RC-75M detail and must be included on the plans.

The following construction considerations should be addressed:

- Coarse Aggregate - A coarse aggregate pad should be constructed only when leveling is required.
- Geotextile Channel Linings - These may be necessary to protect the discharge flow path. If it appears that there may be an issue with scouring from PWFB discharge, line the discharge flow path with Geotextile (Class 4, Type A).
- Pump - Required to get water to the PWFB.
- Lifting Straps - Required to lift the bag when pumping has ceased and/or the bag has reached sediment capacity.

The following considerations should be addressed when determining a possible location for a PWFB:

- PWFBs should be located in a well-vegetated (grassy) area, and discharge onto stable, erosion resistant areas. Where this is not possible, a geotextile (Class 4, Type A) lined flow path should be provided.
- PWFBs are to be located in areas that are accessible by construction machinery for maintenance and removal purposes.
- When the slope of the area where the PWFB is to be located exceeds 5%, a coarse aggregate pad should be constructed for leveling purposes.
- Compost berm or compost filter sock should be installed below bags located within 15 m (50 ft) of receiving stream or where grassy area is not available.

The following construction considerations should be addressed:

- A suitable means of accessing the PWFB with machinery required for disposal purposes must be provided at all times.
- Replace PWFBs when they become half filled with sediment.
- Keep spare PWFBs on site for replacement of those that have failed or are filled.
- Upon detection of any problem with a PWFB or hose between the pump and the bag, cease pumping immediately and do not resume until the problem is corrected or another bag or hose is placed into operation. At no time shall there be multiple hoses attached to a single PWFB.
- PWFBs must be removed from the site and disposed of in an appropriate manner. Cutting bags open and seeding the area is not an acceptable practice.

I. Temporary Slope Pipe. A temporary slope pipe is a flexible or rigid pipe, used prior to permanent drainage structures, installed to convey concentrations of runoff from the top to bottom of disturbed slopes. A typical temporary slope pipe plan and section view is shown on Standard Drawing RC-74M. A temporary slope pipe may be installed to transport stormwater runoff down the face of a cut or fill slope to a stabilized area or an interceptor channel that conveys sediment-laden water to a sediment trap/basin. Temporary slope pipes should be used prior to the installation of permanent facilities and/or permanent stabilization of slopes in accordance with the proposed sequence of work for the project.

In general, when temporary pipes are part of a formal E&SPC Plan design, they should be sized appropriately by determining peak flows from drainage areas and cover types. Table 12.22 is also an acceptable method to size slope pipes. The maximum contributing drainage area to a slope pipe is 2 hectares (5 acres).

Table 12.22 Suggested Minimum Sizes

Drainage Area		Corrugated Pipe Diameter		Minimum Berm Height	
hectare	**acre**	**mm**	**in**	**mm**	**in**
0 to 0.8	0 to 2	300	12	600	24
0.8 to 1.6	2 to 4	375	15	675	27
1.6 to 2.0	4 to 5	450	18	750	30

Reference: *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

Inspection of temporary slope pipes should be done on a weekly basis and after each runoff event. Accumulated sediment should be removed from the entrance of the pipe. Damaged or leaking pipe sections should be repaired immediately.

Adequate outlet protection should be provided as needed at the outlet of the temporary slope pipe. Rock outlet protection design guidance can be found in Section 12.5.K.

J. Storm Inlet Protection. Storm inlet protection provides a method of collecting and/or detaining runoff from disturbed areas to allow sediment to settle before it enters the storm sewer. Storm inlet protection may be constructed around, on, or inserted into an inlet. Storm inlet protection consists of various methods including inlet filters, traps, and berms. Each type differs in application depending on site conditions and type of inlet. Not all designs are appropriate in all cases. The designer must select a design suitable for the project needs and site conditions. Storm inlet protection is not required for inlets tributary to sediment basins and sediment traps.

Storm inlet protection should be considered in the following situations:

- Existing storm sewers in disturbed areas.
- Wherever earth disturbance occurs in an area with a storm sewer system that does not discharge into a functioning sediment trap or sediment basin during construction.
- Wherever the storm sewer system discharges to a detention pond, since detention ponds may not effectively remove sediment prior to discharging.

The following steps should be used to evaluate the project to determine the most suitable method of protection. In addition to the design steps provided below, a downslope berm must be provided for all methods of Storm Inlet Protection for inlets on grade. If the berm would interfere with vehicular traffic, Storm Inlet Protection cannot be used and other sediment control measures should be examined.

Step 1 Determine the contributing drainage area to the inlet.
Step 2 Determine if there will be vehicular traffic in the area.
Step 3 Determine if the inlet will be operational prior to the contributing drainage area being stabilized.

Down gradient berms should be placed downstream of each inlet accepting sediment laden runoff. Do not use berms where they may pose a vehicular hazard or where additional ponding of water may cause flooding and traffic hazards. Refer to Standard Drawing RC-72M for placement of down gradient berms.

Three methods of inlet protection are addressed in this section: Inlet Filter Bags, Concrete Block/Gravel Inlet Protection and Pipe/Gravel Inlet Protection.

1. Inlet Filter Bags. Inlet filter bags (also referred to as inlet sediment sacks) are suitable for drainage areas less than 0.2 hectare (0.5 acre) and areas with limited vehicular traffic, recognizing that ponding may occur creating a hazard. A 150 mm (6 in) sandbag berm should be installed immediately downstream of the inlet to prevent the majority of the runoff from bypassing each inlet. A sandbag berm is not required for inlets in a sump condition as there should be no runoff bypass. Inlet filter bags can be used for inlets with Type C, M or S top units. Refer to Standard Drawing RC-72M for typical use of inlet filter bags.

Inlet filter bags should be inspected weekly and after each rainfall event to ensure that the bag is functioning properly. Any inlet filter bags that become ripped or torn should be removed and properly disposed of and immediately replaced. In addition, any sandbag berms that may become washed out should also be repaired or replaced. Accumulated sediment should be removed when the inlet filter bag reaches one-half maximum capacity. Sediment should be removed and disposed of in accordance with Publication 408, *Specifications*.

2. Concrete Block/Gravel Inlet Protection. Concrete block/gravel inlet protection utilizes a barrier of concrete block overtop of the inlet grate with a gravel and wire mesh filter system to remove sediments from disturbed runoff. Concrete block/gravel inlet protection is suitable for drainage areas less than 0.4 hectare (1 acre) and areas where there is no vehicular traffic. A sandbag or earthern berm should be installed immediately downstream of the inlet to prevent runoff bypass. The berm should be installed 150 mm (6 in) above the height of the proposed block and gravel protection. Additional sandbags may be required upstream of the downstream end of the inlet parallel to the contour to avoid runoff bypass. Berms should not be installed in areas of vehicular traffic. A berm is not required for inlets in a sump condition as there should be no runoff bypass. Concrete block/ gravel inlet protection can be used for inlets with Type C, M or S top units. Refer to Standard Drawing RC-72M for typical use of concrete block/gravel inlet protection.

Concrete block/gravel inlet protection should be inspected after each rainfall event to ensure that the inlet protection is functioning properly. Any concrete blocks or gravel that has been displaced should be immediately repaired. In addition, any sandbag berms that may become washed out should also be repaired or replaced. Accumulated sediment should be removed as necessary. Sediment should be removed and disposed of in accordance with Publication 408, *Specifications*.

3. Pipe/Gravel Inlet Protection. Pipe/Gravel Inlet Protection utilizes corrugated metal pipe (or equivalent), gravel and wire mesh to remove sediment from disturbed runoff prior to entering the inlet. Pipe/gravel inlet protection is suitable for drainage areas less than 0.4 hectare (1 acre) and areas where there is no vehicular traffic. A sandbag or earthern berm should be installed immediately downstream of the inlet to prevent runoff bypass. The berm height should be a minimum of 400 mm (16 in) in height with a minimum of 150 mm (6 in) in freeboard above the top of the filter pipe. Additional sandbags may be required upstream of the downstream end of the inlet parallel to the contour to avoid runoff bypass. Berms should not be installed in areas of vehicular traffic. A berm is not required for inlets in a sump condition as there should be no runoff bypass. Pipe/gravel inlet protection can be used for inlets with Type C, M or S top units. Refer to Standard Drawing RC-72M for typical use of pipe/gravel inlet protection.

Pipe/gravel inlet protection should be inspected after each rainfall event to ensure that the inlet protection is functioning properly. Any pipe or gravel that has been displaced should be immediately repaired. In addition, any sandbag berms that may become washed out should also be repaired or replaced. Accumulated sediment should be removed as necessary. Sediment should be removed and disposed of in accordance with Publication 408, *Specifications*.

K. Outlet Protection: Rock. Rock outlet protection is a temporary or permanent rock lining constructed in the area of an outfall to provide scour protection against discharges from pipes and channels. The purposes are to prevent erosion in areas immediately downstream of pipe and channel outlets and to reduce the velocity of the water. Several types of outlet protection are described in this section. Outlet protection must be provided for the following locations where outlet velocities exceed that capacity of downstream areas to resist erosion:

- Storm drains.
- Sediment traps.

- Sediment basins.
- Stormwater management basins.
- Temporary slope pipes.
- Ditches or channels (temporary or permanent).

For existing facilities, where scour or erosion is occurring at the outlets, place rock as necessary based on the scour limits. Refer to Standard Drawing RC-72M for minimum protection requirements.

1. Rock Basin or Rock Energy Dissipator. Rock basins and rock energy dissipators are used to dissipate energy and control erosion at pipe outlets where flow will remain concentrated. The rock basin should be used where the outlet pipe diameter is less than 900 mm (36 in) and the rock energy dissipator should be used where the outlet pipe diameter is 900 mm (36 in) or larger. When outlet velocities exceed 4.2 m/s (14 ft/s), the top 150 mm (6 in) of the rock lining can be grouted, or another type of velocity reduction measure should be used (e.g., paved energy dissipator, riprap basin, stilling well, etc.). Another measure, such as a riprap basin, paved energy dissipator, or stilling basin, should be used if the outlet velocity exceed 5.7 m/s (19 ft/s). Rock basins and rock energy dissipators should be constructed as shown to Standard Drawing RC-72M.

It should be noted that Rock Basins and Rock Energy Dissipators are conservatively sized. They are designed to handle severe conditions resulting from common pipe and channel installations. Where the design discharge velocity is low and/or space is limited, consideration should be given to the other outlet protection BMPs in this chapter.

2. Rock Apron. Rock aprons are used to dissipate energy and control erosion at pipe outlets. Rock aprons should be constructed as shown to Standard Drawing RC-72M. Rock aprons can be used at the outfall locations mentioned previously in this section and where velocities are less than 4.3 m/s (14.5 ft/s). Rock aprons can be used is areas where a minimum or maximum tailwater condition exists.

The following design guidelines step through a process of evaluating the flow to determine the appropriate riprap size and dimensions of the rock apron.

Minimum tailwater exists when the normal depth of flow in the receiving watercourse, as calculated by Manning's equation, is less than one-half the diameter of the discharge pipe, or where no channel or swale exists at the point of discharge.

- Locate the design discharge (pipe flowing full) along the bottom of Figure 12.20.
- Follow a vertical line to the point where it intersects the first curve corresponding to the diameter of the discharge pipe. From that point follow a horizontal line to the right to determine the minimum d_{50} stone size of the riprap in feet.
- Check the table in Chapter 8, *Open Channels,* Section 8.7 to ensure that the anticipated discharge velocity does not exceed the maximum permissible velocity for the size of riprap obtained. If the anticipated discharge velocity exceeds the maximum permissible velocity, increase the size of the riprap to a size whose permissible velocity is not exceeded.
- Follow the same vertical line mentioned above to the point where it intersects the second curve corresponding to the diameter of the discharge pipe. From that point, follow a horizontal line to the left and read the Minimum Length of the apron (L_a) in feet.
- After the length (L_a) is determined, use it to determine the apron width using the formula:

(Equation 12.2)

$$W = 3D_o + L_a$$

Where: D_o = the outlet pipe diameter, m (ft)
L_a = the length of the apron, m (ft)

Where the apron design width (W) exceeds the downstream watercourse bottom width, a transition zone must be designed and installed downstream from the apron to the watercourse. When the pipe discharges directly into a well-defined channel, the apron should extend across the channel bottom and up the channel banks to an elevation 300 mm (1 ft) above the maximum tailwater depth or to the top of the bank, whichever is less. See to Standard Drawing RC-72M.

If the pipe discharges onto a flat area with no defined channel, the width of the upstream end of the apron should be three times the diameter of the outlet pipe. The width of the downstream end of the apron should be equal to the pipe diameter plus the length of the apron. The bottom grade of the apron should be constructed on a flat grade (0%). The invert of the apron should be equal to the invert of the receiving channel. If the pipe discharges into a well-defined channel, the side slopes should be no steeper than 1V:2H (2H:1V).

Maximum tailwater exists when the depth of flow in the receiving water course, as calculated by Manning's equation, is greater than one-half the diameter of the pipe.

- Locate the design discharge (pipe flowing full) along the bottom of Figure 12.21.
- Follow a vertical line to the point where it intersects the first curve corresponding to the diameter of the discharge pipe. From that point follow a horizontal line to the right to determine the minimum d_{50} stone size of the riprap in feet.
- Check the table in Chapter 8, *Open Channels,* Section 8.7 to ensure that the anticipated discharge velocity does not exceed the maximum permissible velocity for the size of riprap obtained. If the anticipated discharge velocity exceeds the maximum permissible velocity, increase the size of the riprap to a size whose permissible velocity is not exceeded.
- Follow the same vertical line mentioned above to the point where it intersects the second curve corresponding to the diameter of the discharge pipe. From that point, follow a horizontal line to the left and read the minimum length of the apron (L_a) in feet. After the length (L_a) is determined, use it to determine the apron width using the formula.

Where the apron design width (W) exceeds the downstream watercourse bottom width, a transition zone must be designed and installed downstream from the apron to the watercourse. When the pipe discharges directly into a well-defined channel, the apron should extend across the channel bottom and up the channel banks to an elevation 300 mm (1 ft) above the maximum tailwater depth or to the top of the bank, whichever is less.

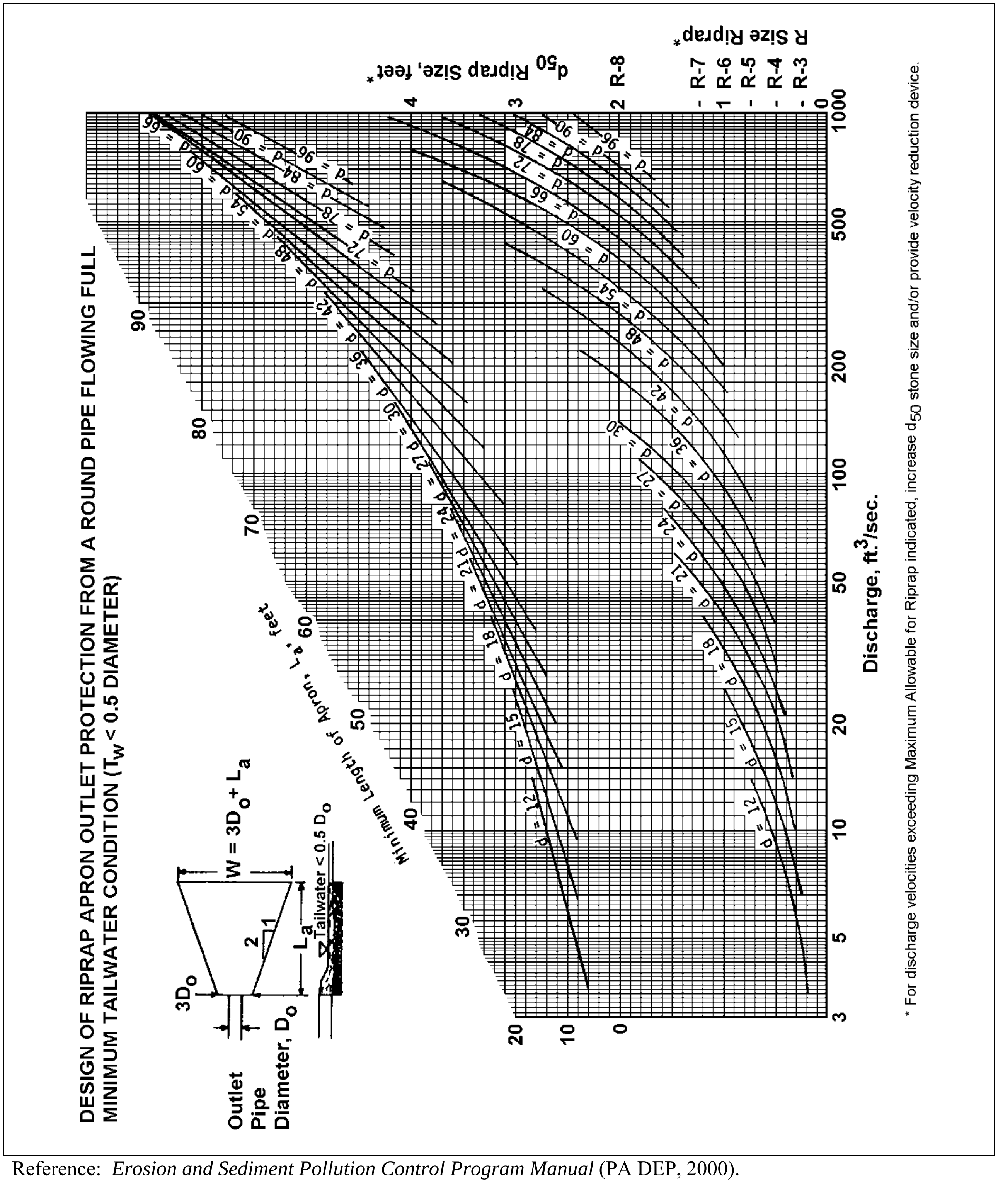
If the pipe discharges onto a flat area with no defined channel, the width of the upstream end of the apron should be three times the diameter of the outlet pipe. The width of the downstream end of the apron should be equal to the pipe diameter plus the length of the apron. The bottom grade of the apron should be constructed on a flat grade (0%). The invert of the apron should be equal to the invert of the receiving channel. If the pipe discharges into a well-defined channel, the side slopes should be no steeper than 1V:2H (2H:1V).

(Equation 12.3)

$$W = 3D_o + 0.4L_a$$

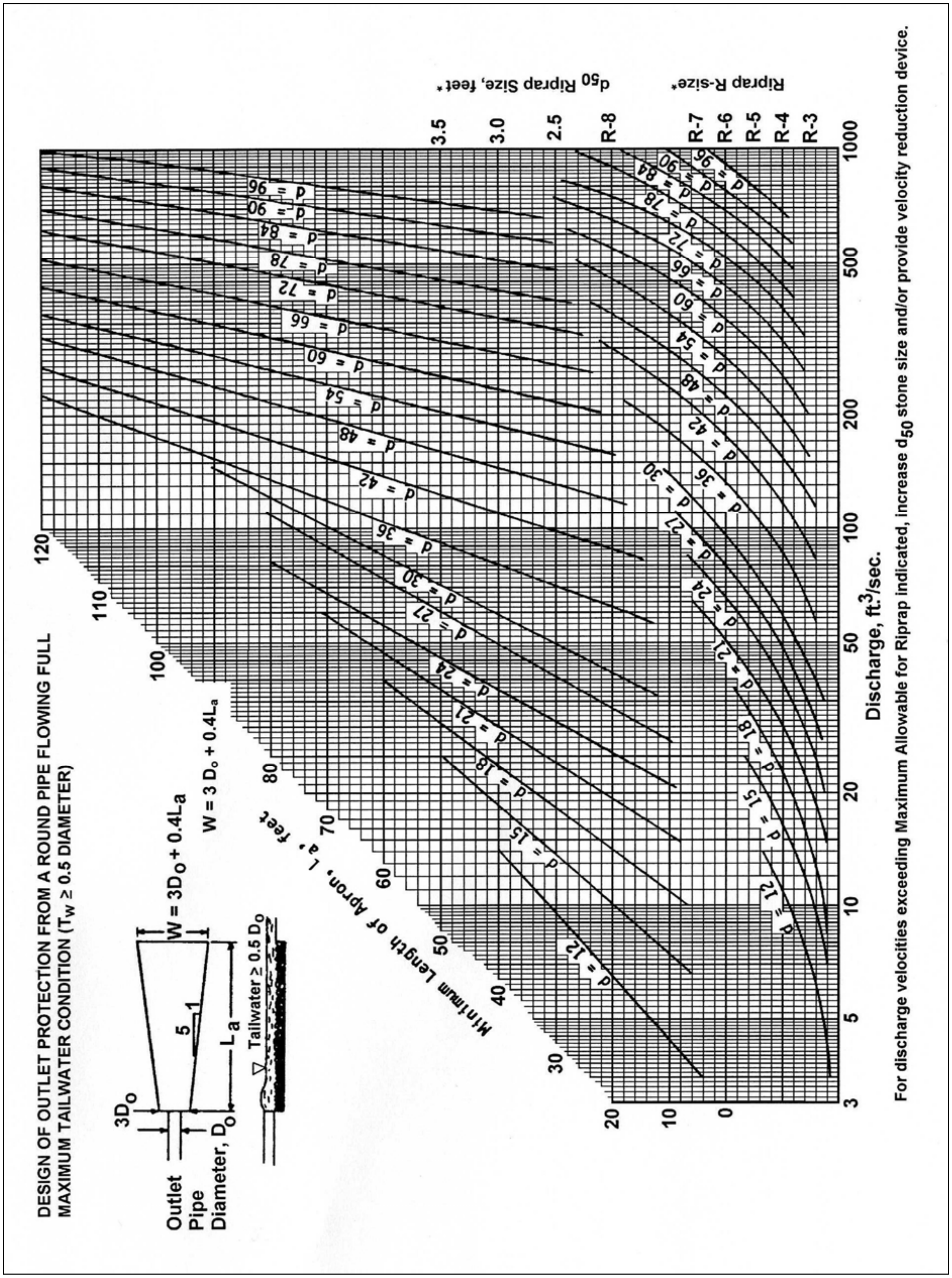
Where: D_o = the outlet pipe diameter, m (ft)
L_a = the length of the apron, m (ft)

Figure 12.20 Riprap Apron Design, Minimum Tailwater Condition



Reference: *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

Figure 12.21 Riprap Apron Design, Maximum Tailwater Condition



Reference: *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

3. Paved Energy Dissipators. Paved Energy dissipators basins are used to dissipate energy and control erosion where discharge velocities are greater than 4.3 m/s (14.5 ft/s). Refer to the HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006) for guidance on selecting and designing paved energy dissipators. On Standard Drawing RC-72M a typical paved energy dissipator is shown.

4. Riprap Basins. Riprap basins are used to dissipate energy and control erosion where discharge velocities are greater than 4.3 m/s (14.5 ft/s). Refer to the HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006) for guidance on selecting and designing riprap basins.

L. Outlet Protection: Stilling Well. A stilling well is a type of concrete energy dissipator constructed below grade at the outlet end of culverts and pipes. Stilling wells are used to reduce the velocity and energy of a concentrated discharge of water at an outlet. Stilling wells should be considered when discharge velocities at new culvert or pipe outlets would be sufficient to erode the downstream slope or channel unless an energy dissipation structure is installed. Specific situations include:

- Culvert outlets.
- Outlet pipes.
- Slope pipes
- Conditions where water needs to be slowed prior to entering a receiving channel.

Stilling wells should be considered in areas where little debris is expected. Placing them in non-forested areas proves to be most effective.

For safety reasons, stilling wells should be designed with a removable grate that can be locked into position.

Weep holes can be added to allow for infiltration, if necessary.

The type of stilling well outlined in this section is the Corps of Engineers Stilling Well. Design methods and procedures outlined below are adopted from the *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000) and HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006). After the above considerations have been weighed and the decision has been made to use a stilling well, the following step-by-step procedure may be used to guide the designer to complete the design of a stilling well.

1. Determine the maximum design discharge for the outlet in which a stilling well is proposed.

2. Using the Pipe Diameter (D) in m and feet and Design Discharge (Q) in m^3/s or cfs, determine the Well Diameter (DW) from Figure 12.23 and Figure 12.24.

3. Using the culvert slope (V:H) determine h_1/D_W from Figure 12.25. Variables h_1 and D_W are defined in Figure 12.25.

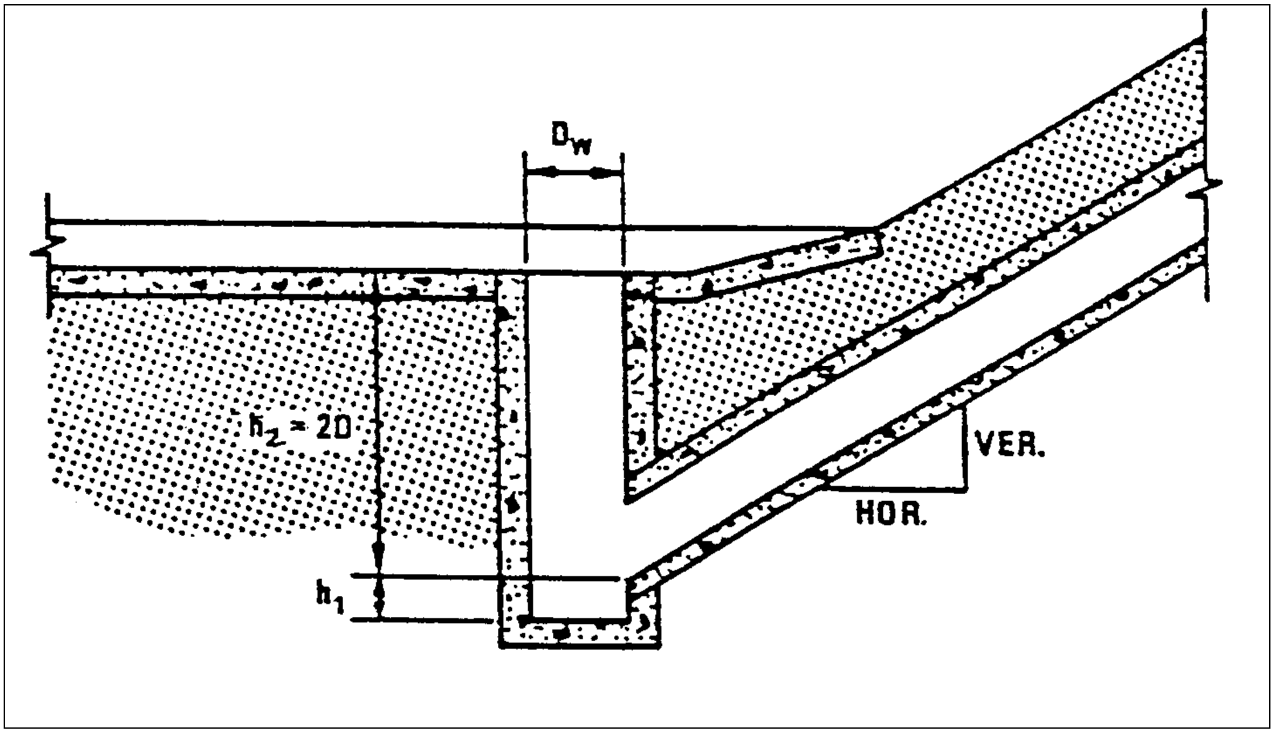
4. Calculate the Depth of Well Below Invert (h_1) in feet by multiplying h_1/D_W by the diameter of the well (DW).

5. Calculate the minimum depth of the well using the equation provided in Figure 12.22. Minimum depth of the well (h_2) above the invert is 2D. Note: Increasing this depth will increase the efficiency of the well.

6. The total depth of the well (h_w) can be calculated using $h_w = h_1 + h_2$.

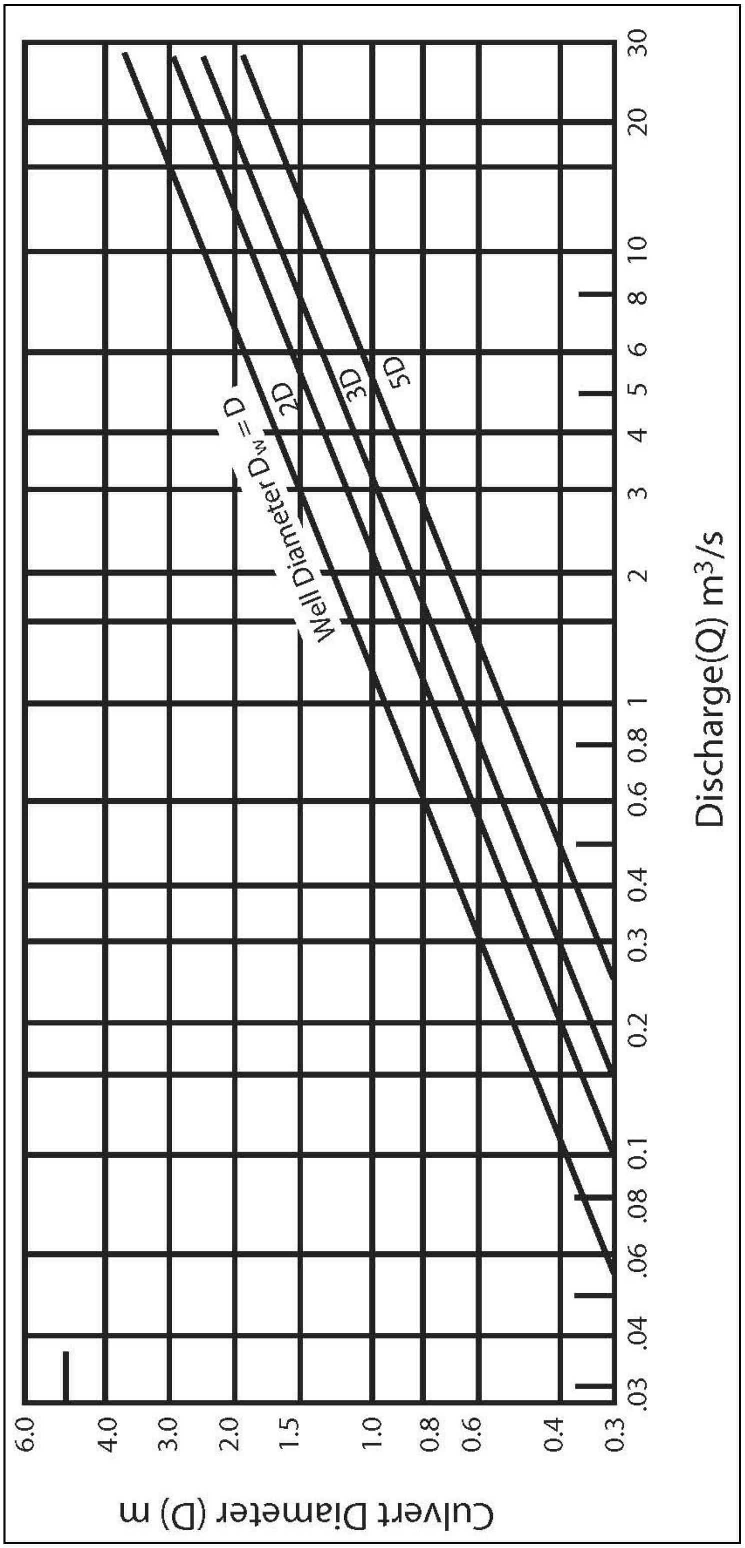
7. Riprap protection or other types of channel protection should be provided around the stilling well outlet and for a distance of $3D_W$ downstream.

Figure 12.22 Stilling Well (Typical)



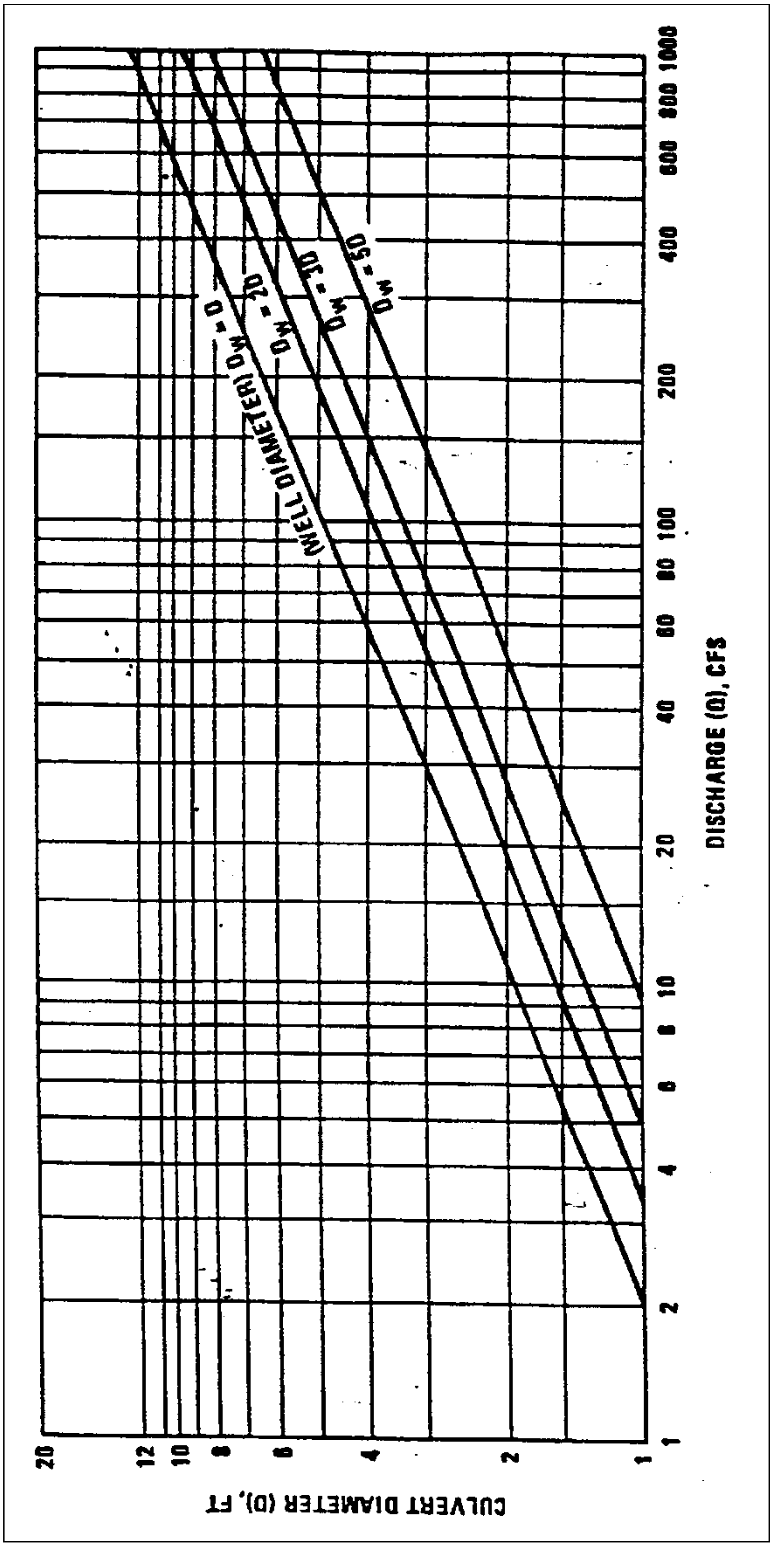
Reference: HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006).

Figure 12.23 Stilling Well Diameter (Metric)



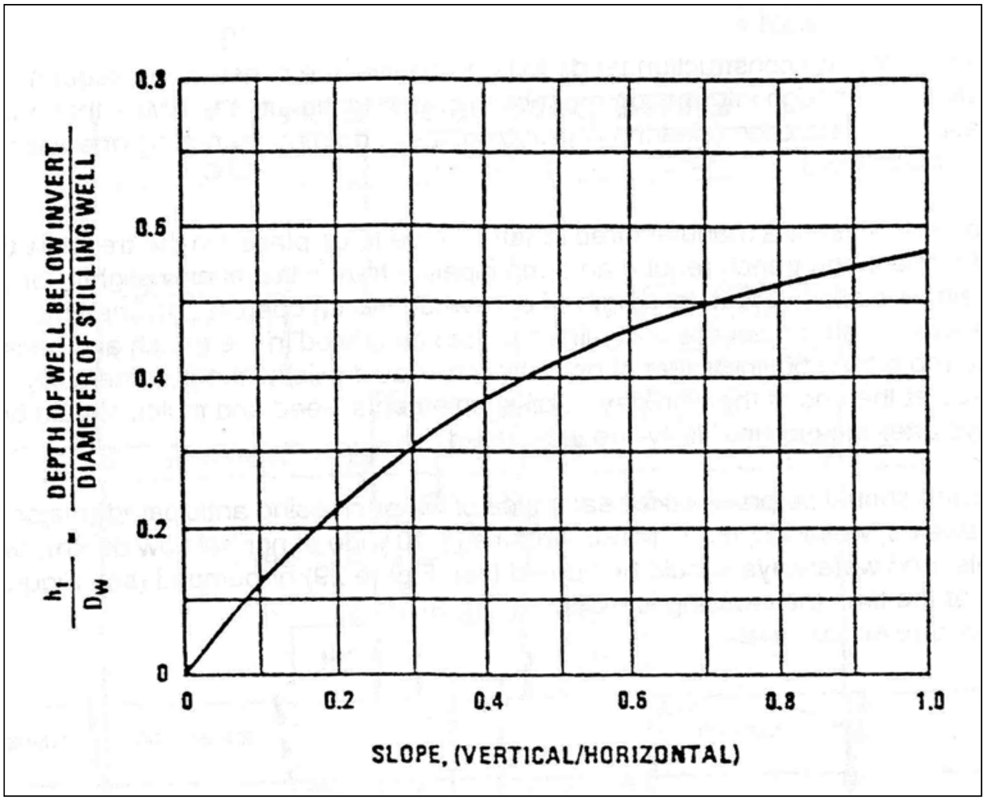
Reference: HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006).

Figure 12.24 Stilling Well Diameter (U.S. Customary)



Reference: HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006).

Figure 12.25 Depth of Stilling Well Above Invert



Reference: HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006).

M. Diversion Ditch. A diversion ditch is a channel used to convey upland water around work areas. A diversion ditch might outlet to grassed waterways, at-grade stabilization structures, natural watercourses and storm sewers.

Diversion ditches may be used where:

- The flow would damage the work or work area if not diverted.
- Excessive runoff from upstream drainage areas would interfere with the efficient operation of E&SPC or PCSM controls.
- Runoff to construction areas, cut slopes, or other temporarily disturbed sites might accelerate erosion and sedimentation problems, or interfere with the establishment of vegetation.
- Sediment-laden water needs to be directed to a specific BMP such as a Sediment Trap or Sediment Basin.

Diversion ditches are NOT appropriate in the following situations:

- Below sediment producing areas unless measures to prevent sediment accumulation are installed with or before the diversion ditches.
- In place of terraces on land where terracing is needed to control erosion.

Determine the location of the diversion ditch considering the following:

- Construction Sequencing and Phasing. Select a location that minimizes interference with construction activities.
- Right-of-Way. Select a location that will minimize right-of-way requirements and impacts.
- Earthwork. Select a location with the least overall quantity of excavation.
- Soil Type. If possible, select a location where the diversion ditch is constructed in erosion resistant soil.

Diversion ditches are to be designed to convey the peak discharge from the 2-year frequency storm event. In Special Protection watersheds, the 5-year design storm should be used for diversion ditches. To calculate the capacity of the diversion ditch, refer to Chapter 8, *Open Channels*.

Most diversion ditch cross sections are trapezoidal or triangular in shape with rounded corners. For design purposes, a trapezoidal or triangular representation is sufficient. If available channel linings are found to be inadequate for the computed velocity, try a wider channel. The diversion ditch should be designed to have stable side slopes. The channel depth to the top of the berm should be constructed a minimum of 10% greater than the final design depth to account for settling. The berm should have a minimum top width of 1.2 m (4 ft) at the design elevation. A freeboard of not less than 150 mm (6 in) should be provided for the design discharge. A larger freeboard may be required where unstable flow conditions exist. For channels greater than 600 mm (2 ft) total depth, the freeboard should be one-quarter the total depth.

Channel grades may be uniform or variable. Incorporate appropriate measures to dissipate energy and prevent scour at flow transitions (see Section 12.5.K, Outlet Protection: Rock, and Section 12.5.N., Channel Lining BMPs). Bed slopes may not be averaged when determining flow velocity, capacity, or shear stress. Diversion Ditches must be stabilized prior to receiving flow. This may require additional lining. Refer to the Channel Lining BMP for design specifics and options.

Ensure there is a stable outlet for the diversion ditch. A diversion ditch might outlet to grassed waterways, at-grade stabilization structures, natural watercourses and storm sewers.

N. Channel Lining. Channel lining is defined as a temporary or permanent erosion-resistant protection placed on channel beds and side slopes to prevent scour and erosion. Channels are lined in order to convey runoff without damage from erosion or flooding. Channel lining reduces sedimentation downstream and contributes to overall water quality. Constructed channels and ditches should be lined with an erosion resistant lining. The type of lining is contingent upon several factors including runoff velocity, soil type, and channel function. Options for channel liners include grass (vegetated channels), sod, RECPs, rock, concrete, and other methods. See Chapter 8, *Open Channels,* for comparison of channel lining methods.

A protective liner is required if the channel is located in a Special Protection watershed (HQ/EV) or if shear stress exceeds the maximum permissible for the type of soil present. Protective linings for channels and streams can be very expensive; therefore, a special effort should be made to consider the lowest-cost erosion control, including future maintenance, for the particular location. Recommended erosion control measures for ditch and channel protection are discussed in Chapter 8, *Open Channels*.

O. Rock Barrier. A rock barrier is a small, temporary, stone dam installed across a channel or swale. The primary purpose of a rock barrier is to remove sediment originating from flow in a channel before vegetation is fully established.

Rock barriers should be considered for the following situations:

- To limit sedimentation in runoff within constructed channels until a protective lining is installed and operational.
- During a temporary disturbance within the channel.
- Below construction work within an existing stream channel while flow is being diverted past the work area. In such cases, place the filter between the work area and the discharge from the bypass system.
- Where channels are 600 mm (2 ft) or greater in depth.

Rock barriers may be used in combination but are not intended to be installed in place of other E&SPC controls such as:

- Sediment basins and sediment traps.
- Appropriate channel linings. Use of rock barriers in this manner often results in overtopping of the channel during storm events, scouring of the channel bottom below the filter, and/or erosion of the channel side slopes as sediment deposits build up behind the filter.

- Adequate protective lining in sediment basin emergency spillways. If rock barriers are used in this situation, the effective discharge capacity of the spillway can be reduced and will increase the possibility of embankment failure.

Rock barriers should be designed as outlined in this manual and in accordance with Publication 72M, *Roadway Construction Standards*, and Publication 408, *Specifications*. A typical rock barrier design is shown to Standard Drawing RC-73M. The height of the filter should be equal to half the total depth of the channel. The center depression should be equal to one-half of the filter height or 150 mm (6 in). Rock barriers should not be placed within channels to reduce flow velocity or within channels less than 600 mm (2 ft) in depth. Rock barriers should be designed with a 300 mm (1 ft) thick layer (filter) of AASHTO No. 57 aggregate to be placed on the upstream side of the barrier. In Special Protection watersheds, a 150 mm (6 in) layer of compost should be placed on top of the filter stone.

Maintenance of rock barriers during construction should be considered. Remove the rock barrier and accumulated sediment upon final stabilization of the channel. The rock barrier should be inspected weekly and after each rainfall event. If the rock becomes eroded around the sides of the rock barrier, the filter should be repaired immediately. Sediment should be removed when accumulation reaches one-half the height of the filter at the center of depression. The rock barrier should also be replaced if the filter stone becomes clogged.

P. Sediment Trap. A sediment trap is a small, temporary ponding area created by construction of an earthen embankment. Two types of sediment traps are commonly used: an embankment sediment trap, and a riser sediment trap. The embankment sediment trap discharges through a stone filter that is located within the embankment of the trap. An embankment sediment trap can also discharge through a stone filter that is located over a Type M inlet. A riser sediment trap discharges through a riser and outlet pipe that is located within the embankment of the trap.

The primary purpose of sediment traps is to detain sediment-laden runoff from small, disturbed areas and provide adequate settling time to allow the majority of sediment and other particulates to settle out prior to discharge from the construction site. Sediment traps are appropriate for drainage areas 2.0 hectare (5.0 ac) or less. Embankment sediment traps are primarily designed to function as temporary facilities. If, after evaluation, a sediment trap is specified in the area where a permanent stormwater management basin is to be located, a riser sediment trap should be used. Sediment traps may also be used for the dewatering of excavation holes in lieu of a pumped water filter bag where practical. Note this is not an acceptable practice when water levels inside the sediment trap are at (or higher) than the cleanout elevation or top of the sediment storage zone.

The following should be considered when locating a sediment trap:

- Aligned the sediment trap with natural drainage patterns as much as practicable.
- Allow access for removing sediment and disposing of it properly under typical weather conditions.
- Sediment traps should avoid impacts to wetlands and streams unless impracticable.
- A sediment trap should be located such that it is not tributary to other sediment traps, collector ditches, or sediment basins.
- Allow sufficient space to construct and maintain the sediment trap. Temporary construction easements or additional right-of-way may be required. If discharge from a sediment trap cannot reach a channel within the right-of-way or cannot be contained within an implied stormwater easement, a temporary stormwater easement may be necessary.
- Collection channels carrying sediment-laden water should be directed to a sediment trap or basin.

The following is a list of design constraints for a sediment trap. Design methods and procedures are derived from the *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000). Refer to Standard Drawing RC-71M for typical details of embankment and riser sediment traps.

- Sediment trap sizing is based on the total contributing drainage area. The maximum permissible contributing drainage area, including the trap itself, is 2.0 hectare (5.0 ac). The contributing drainage area includes all areas that will be tributary to the trap at any given time during the life of the sediment trap.
- The minimum volume of the sediment trap is 140 m^3/ha (2000 ft^3/ac) of contributing drainage area. This is divided into two parts: Dewatering Volume and Sediment Storage Volume. Both volumes are determined by the contributing drainage area.

  - Dewatering Volume: A minimum of 90 m^3/ha (1300 ft^3/ac).
  - Sediment Storage Volume: A minimum of 50 m^3/ha (700 ft^3/ac).
- Maximum exterior and interior embankment side slopes are 1V:2H (2H:1V).
- The maximum spillway side slope is 1V:2H (2H:1V).
- Sediment traps must be able to dewater the dewatering volume completely. In areas where total dewatering is required, adequate filtering of the sediment storage area must be provided.
- Minimum depth is 0.6 m (2 ft). (Minimum 0.3 m (1 ft) for sediment storage and a minimum of 0.3 m (1 ft) for dewatering zone).
- Maximum constructed embankment height is 1.5 m (5 ft) unless the embankment is constructed as a permanent stormwater management basin (refer to riser sediment trap). If the embankment height is greater than 1.5 m (5 ft), safety regulations may apply and should be investigated.
- Minimum embankment top width is 1.5 m (5 ft).
- The flow length is to be measured at the elevation which corresponds to the top of the dewatering zone. The minimum flow length (L) is 3.0 m (10 ft). The minimum flow length to width ratio is 2:1. Equation 12.4 may be used for computing minimum length in traps that are generally rectangular. For traps that have an irregular shape, the best way to determine average width is to divide the surface area at top of dewatering with the maximum length of the trap at the same elevation. Then the ratio can be verified. Where 2:1 ratio is not possible by grading only, a baffle may be used to increase flow length to the required 2:1 ratio.

(Equation 12.4)

$$L_{(min)} = 1.41(SA)^{0.5}$$

Where: $L_{(min)}$ = Minimum Flow Length – m (ft)
SA = Surface Area at the top of the dewatering volume – m^2 (ft^2)

Other general design considerations include:

- The water from the contributing drainage area may enter the sediment trap by any appropriate method. If the runoff is conveyed to the sediment trap by a collector channel or combination of slope pipe and channel, the channel and/or pipe should be sized by the methods indicated in Publication 13M, Design Manual, Part 2, *Highway Design*, Chapter 10.
- Where stormwater runoff from disturbed areas enters a sediment trap from different directions, consider routing flows from the various areas to a single inlet into the sediment trap.
- The water discharged from a sediment trap must be conveyed to a downstream watercourse by means of an adequately designed channel. When the conveyance channel intersects with the downstream watercourse, appropriate methods should be used to prevent the banks of the receiving water from erosion or scour. An earthen level spreader below a sediment trap is not an acceptable practice.
- During construction, a stake should be placed in the center of the sediment trap. This stake is marked with the height corresponding to the top of the sediment storage volume (clean out elevation). Accumulated sediment should be removed from the sediment trap whenever it reaches the marked elevation on the clean-out stake. Removed sediment must be disposed of per appropriate regulatory requirements.

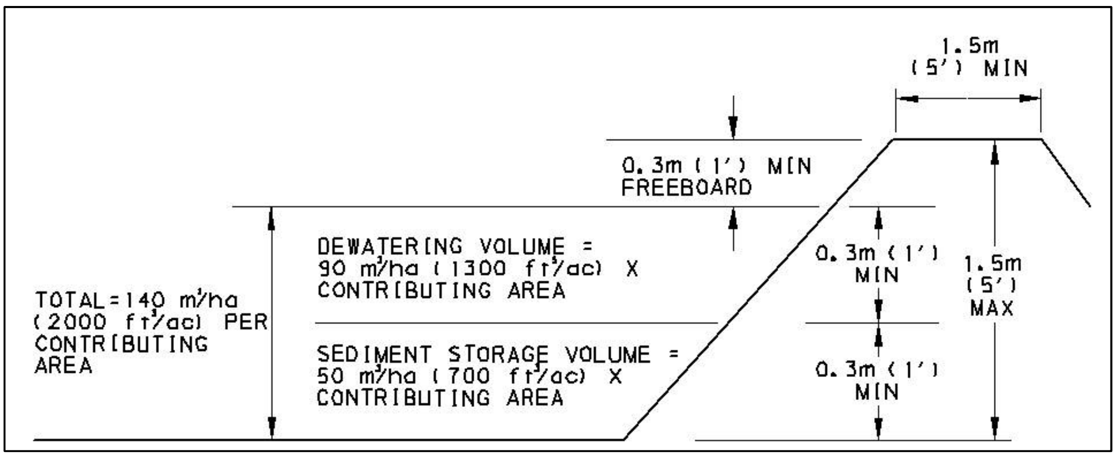
The following design considerations are specific to Embankment Sediment Traps (also refer to Figure 12.26):

- Minimum embankment spillway crest elevation is the elevation at which the required 140 m^3/ha (2000 ft^3/ac) (contributing drainage area) storage capacity is provided.
- Provide a minimum of 300 mm (1 ft) freeboard above the embankment spillway crest elevation (top of dewatering volume). This will be considered the minimum top of embankment elevation.
- Minimum embankment spillway width is 2 times the height of the spillway crest or 1.5 times the total contributing hectares (2 times the total contributing acreage), whichever is greater.
  - Example: an embankment sediment trap has a drainage area of 1.8 hectare (4.5 ac) with a bottom invert of 332.23 m (1090 ft) and spillway crest elevation of 333.45 m (1094 ft). From the spillway height portion of the equation above, the calculated spillway width is 2.44 m (8 ft). However, from drainage area portion of the equation above, the calculated spillway width is 2.7 m (9 ft). The

spillway width must be greater of the two results; therefore, the spillway width should be 2.7 m (9 ft).

- The entire spillway is Rock, Class R-3. The interior of the spillway is faced with a 150 mm (6 in) layer of No. 57 coarse aggregate to help facilitate detention and filtration. In Special Protection watersheds, a 150 mm (6 in) layer of compost is placed on top of the No. 57 coarse aggregate. Geotextile, Class 3, Type B should be securely staked on top of the No. 57 course aggregate, or the compost layer in Special Protection watersheds, up to the top of the sediment storage volume (clean-out elevation). Any excess geotextile should be staked to the bottom of the sediment trap.
- Refer to Standard Drawing RC-71M for typical details of an embankment sediment trap around a Type M inlet. A 19 mm (3/4 in) pressure treated plywood box with 50 mm by 50 mm (2 in x 2 in) pressure treated corner posts is set into the inlet grate offsets. A 600 mm (2 ft) minimum ring of No. 57 Coarse Aggregate is placed around the exterior of the plywood riser box to facilitate detention and filtration. There are ten 25 mm (1 in) perforations per vertical 300 mm (1 ft) of plywood riser. Geotextile, Class 3, Type B should be securely staked on top of the No. 57 course aggregate up to the top of the sediment storage volume (clean-out elevation). Any excess geotextile should be staked to the bottom of the sediment trap.

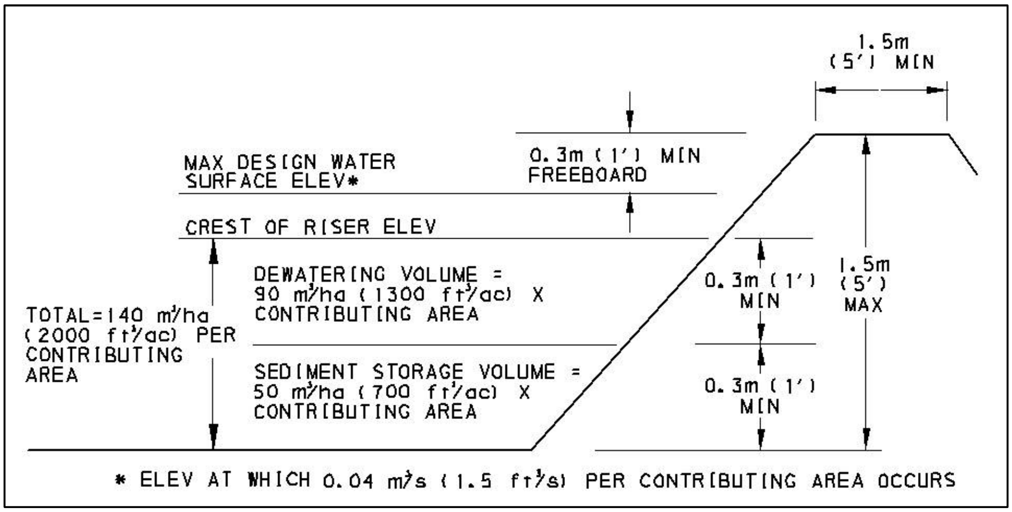
Figure 12.26 Sediment Trap (Embankment)



The following design considerations are specific to Riser Sediment Traps (also refer to Figure 12.27):

- Wherever a sediment trap discharges down a long or steep slope, consideration should be given to using a riser type spillway sediment trap (riser) in conjunction with a temporary slope pipe and adequately designed outlet protection.
- Minimum riser spillway crest elevation is the elevation at which the required 140 m^3/ha (2000 ft^3/ac) (contributing drainage area) storage capacity is provided.
- Perforations in the riser to dewater the trap should be no more than one 25 mm (1 in) perforation per vertical 300 mm (1 ft) of riser with the lowest perforation at the sediment storage volume elevation.
- The design discharge capacity of the riser and outlet pipe should be a minimum of 0.04 m^3/s per ha (1.5 cfs per acre).
- Minimum riser diameter should be 1.25 times outlet pipe diameter and should not be smaller that 300 mm (1 ft) in diameter.
- Provide a minimum of 300 mm (1.0 ft) freeboard above the maximum designed discharge capacity as defined above. This will be considered the minimum top of embankment elevation. It should be noted than an overflow spillway is not required for a riser type sediment trap. If constructed within a permanent stormwater management basin that includes an overflow spillway, the overflow spillway must be a minimum of 150 mm (6 in) above the riser crest elevation.
- Adequately sized outlet protection must be provided at end of the outlet pipe from a riser sediment trap.

Figure 12.27 Sediment Trap (Riser)



Include appropriate references details and notes for sediment traps from Publication 408, *Specifications,* and Publication 72M, *Roadway Construction Standards*. Provide dimensions and elevations to the contractor in a Summary Table (refer to Figure 12.28) on the plans with the sediment trap details.

Figure 12.28 Example Embankment Sediment Trap Summary Table

SEDIMENT TRAP (EMBANKMENT) SUMMARY TABLE

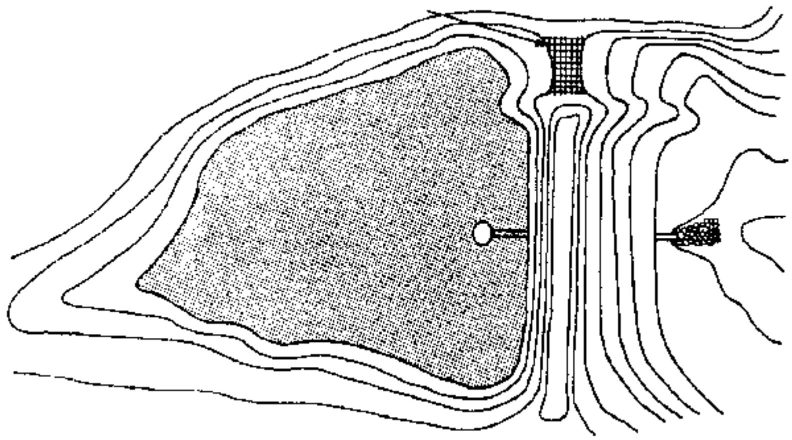
SEDIMENT TRAP No.	LOCATION	BOTTOM ELEVATION (A)	TOP OF EMBANKMENT ELEVATION (B)	CLEANOUT ELEVATION (C)	TOP OF SPILLWAY ELEVATION (D)	SPILLWAY WIDTH (E)
ST-1	SR XXXX STA XXXX+XX, XX	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
ST-2	SR XXXX STA XXXX+XX, XX	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
ST-3	SR XXXX STA XXXX+XX, XX	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X

Inspections of sediment traps should be done on a weekly basis and after each runoff event.

Q. Sediment Basin. A sediment basin is a large, temporary ponding area created by construction of an earthen embankment with an outlet structure (riser) and pipe outlet. A sediment basin discharges through an outlet structure and/or emergency spillway that is typically located within the embankment of the basin (see Figure 12.29).

In general, the primary purpose of a sediment basin is to detain sediment-laden runoff from large disturbed areas and provide adequate settling time to allow the majority of sediment and other particulates to settle out prior to discharge from the construction site. A sediment basin can be used as a perimeter control that could allow the contractor to work within the contributing drainage area without staged construction. Sediment basins are appropriate for drainage areas larger than 2.0 hectare (5.0 ac) and less than 40.0 hectare (100.0 ac). If the contributing drainage area is 2.0 hectare (5.0 ac) and less, a sediment trap or other appropriate BMP should be used. Sediment basins are designed to function as temporary facilities; however, they are often incorporated into the PCSM System upon completion of the project. In the latter case, the sediment basin is converted to a permanent stormwater management basin. Sediment basins may also be used for the dewatering of excavation holes in lieu of a pumped water filter bag where practical. It should be noted that this is not an acceptable practice when water levels inside the sediment basin are at (or higher) than the cleanout elevation or top of the sediment storage zone.

Figure 12.29 Sediment Basin



When locating a sediment basin, the following considerations should be evaluated (Refer to Figure 12.32):

- The contributing drainage area is larger than 2.0 hectare (5.0 ac) and less than 40.0 hectare (100.0 ac). If the contributing drainage area is 2.0 hectare (5.0 ac) or less a sediment trap or another acceptable BMP(s) should be used.
- The natural drainage patterns have been studied and the sediment basin is in a location appropriate to the natural drainage pattern.
- The sediment basin is located to allow access for removing sediment and disposing of it properly under typical weather conditions.
- If a permanent stormwater management basin is planned for the site, consider locating the sediment basin in the same area as this permanent structure to enable the conversion of the sediment basin to a stormwater basin at the end of construction.
- There is sufficient space to construct and maintain the sediment basin. Temporary construction easements or additional right-of-way may be required. If discharge from a sediment basin cannot reach a channel within the right-of-way or cannot be contained within an implied stormwater easement, a temporary stormwater easement may be necessary.
- Collection channels carrying sediment-laden water should be directed to a sediment trap or sediment basin.
- Sediment basins should avoid impacts to wetlands and streams unless impracticable.
- The sediment basin(s) should be located such that it is not tributary to other sediment basins, collector ditches, or sediment traps.

After the above considerations have been weighed and the decision to use a sediment basin has been made, the following is step by step list of procedures that may help the designer to complete the design of a sediment basin:

1. Determine the overall watershed classification that the drainage area to the sediment basin is within. This will help the designer to determine the correct volumes required for design. For example if the basin is in a Special Protection watershed (i.e., HQ or EV), then certain volume reductions are not applicable to the design. The designer can obtain the watershed classification information by contacting PA DEP or the CCD office in which the project site is located. Watershed classifications are also found online at www.pacode.com where the designer can browse for the watershed under PA Code, Title 25, Chapter 93.

2. Determine the type of sediment basin that is most applicable to the site needs. There are three basic types of sediment basins. Refer to Publication 408, *Specifications* and Publication 72M, *Roadway Construction Standards* for construction details and see to Standard Drawing RC-71M.

a. Temporary sediment basin. This type of sediment basin will be installed to control runoff during the construction period and then removed at the completion of earth moving activities once the site has been stabilized. This type of sediment basin will not be converted to a permanent stormwater management basin. Typically the outlet structure configuration of this type of sediment basin consists of a Corrugated Metal Pipe (CMP) riser that is attached directly to an outlet pipe.

b. Sediment basin located within a permanent stormwater management basin. This type of sediment basin will be converted after earth moving activities cease and the site is stabilized. When locating a sediment basin in this configuration, there are typically two scenarios that fall under this category. This first is that the permanent outlet pipe is installed through the embankment and a temporary CMP riser is attached to it. Under this scenario, the permanent out structure will be installed when the basin is converted after the earth moving activities are completed and the site is stabilized. The second is where the permanent outlet structure and outlet pipe are installed and a temporary riser configuration is attached to the permanent outlet structure. It should be noted that if this scenario is used, it will be beneficial to coordinate permanent outlet structure design (Chapter 14, *Post Construction Stormwater Management*) with the design requirements for erosion control (i.e., top of structure and emergency spillway elevations).

3. After the type of sediment basin has been determined, then the designer may begin the iterative process of designing the basin. Several factors are in play when designing. It may be beneficial to use software that is designed to help the designer in basin modeling or create a spreadsheet for easy data manipulation. This iterative process can be achieved by following the suggested procedures listed below:

Step 1: Assume a "footprint" for the sediment basin and determine the total contributing area and the total disturbed area. Then determine volume requirements relative to the watershed and type of basin that is being designed. The volume requirements are listed below.

Step 2: Begin the proposed contouring process. Before starting this step, note that sediment basins should have a minimum flow length to width ratio of 2:1 at the top of the dewatering volume elevation. Refer to flow length to width ratio requirement below. Draw the proposed contours and verify that the volume requirements calculated in the step above are met by obtaining elevation/area information from each of the proposed contours that were drawn. If the volume requirements are not satisfied, then repeat this process again until they are. Note, the embankment should not exceed 4.5 m (15 ft), measured from the inside invert of the basin to the top of the embankment. Otherwise, it will be subject to additional permitting requirements (i.e., dam) by PA DEP and/or USACE. Also, note that it may be beneficial to make the assumption during this step that the total volume requirement defined below (i.e., top of dewatering) is approximately 1.0 m (3.0 ft) below the top of the embankment.

Step 3: After the proposed contours have been established, verify that the drainage area that was delineated based on the assumed "footprint" for the basin in Step 1 above is still valid. If not, adjust the drainage area and then repeat the previous steps again.

Step 4: Outlet Design Modeling. Now the designer may begin the outlet structure modeling process. Using the design criteria listed on the following pages, perform hydraulic calculations for the sediment basin. When performing this step, drawdown calculations must be performed simultaneously to verify that basin will dewater between 2 and 7 days. Note that there are additional requirements for drawdown when the basin is located within a Special Protection watershed. Also note that the emergency spillway may be included to meet the required minimum discharge rate of 0.14 m^3/s (2.0 cfs) per total contributing hectare (acre). This step may take several iterations to match the outlet structure perforation configuration to the drawdown (dewatering) requirements, which are noted on the following pages.

Step 5: Emergency Spillway Design. Every sediment basin must have an emergency spillway unless the basin is located in an infield of a circular exit in which it is surrounded by impervious pavement. If hydraulic calculations have not already been performed to size the emergency spillway, then they should be completed during this step.

Step 6: Freeboard. Verify that 0.6 m (2.0 ft) of freeboard has been provided above the maximum water surface elevation. The maximum water surface elevation corresponds to the water surface elevation achieved when the minimum discharge rate, defined in Step 4 above, is met. If this has not been achieved, go back to Step 2.

Step 7: Anti-Seep Collar. Now the designer can perform anti-seep collar calculations. Design requirements and procedures for this step are indicated on the following pages.
Step 8: Outlet Protection. Size outlet protection accordingly. Refer to Section 12.5.K.

In general, design criteria listed below is derived from the *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000).

The following design guidelines are a simplified approach to sediment basins. Detailed hydraulic calculations are not provided and hydraulic routing is not performed in this guidance.

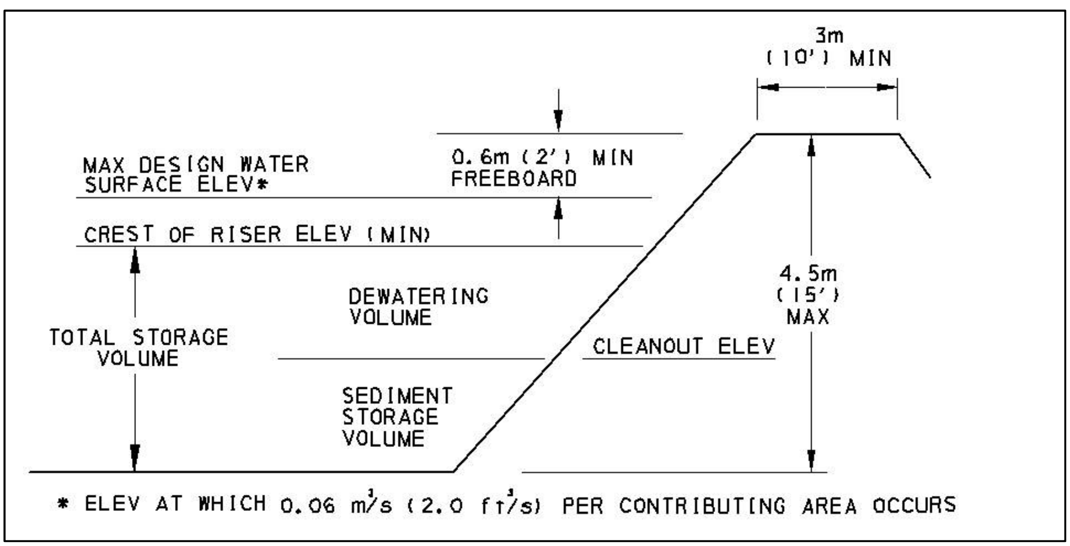
General Requirements:

- The horizontal components of the sediment basin side slope for the embankment must add to a minimum of 5.0 (i.e., interior side slope is 1V:2H (2H:1V) and exterior side slope is 1V:3H (3H:1V)). Note, if sediment basin(s) is located in an area adjacent to traffic (i.e., ramp infield, or along side roadway), side slopes may not be steeper than 1V:3H (3H:1V).
- Maximum embankment height is 4.5 m (15.0 ft), measured from the inside invert of the basin to the top of the embankment. If the embankment is greater than this height, additional permits from PA DEP and/or USACE will be required.
- The minimum top width of a sediment basin is 3.0 m (10.0 ft).

Volume Requirements:

- Sediment basin sizing is based on the total contributing drainage area and the disturbed area within total contributing area. The maximum permissible contributing drainage area, including the basin itself, is 40.0 hectare (100.0 ac). The contributing drainage area includes all areas that will be tributary to the basin at any given time during the life of the sediment basin (Refer to Figure 12.30).

Figure 12.30 Sediment Basin Volume



- The minimum sediment storage volume of the sediment basin is 70 m^3 (1000 ft^3) per disturbed hectare (acre). The corresponding elevation of this volume requirement is the cleanout elevation of the sediment basin.
- The dewatering volume of the sediment basin is 350 m^3 (5000 ft^3) per total contributing hectare (acre). The following reductions can be utilized, however the minimum required dewatering volume is 250 m^3 (3600 ft^3) per total contributing hectare (acre). If the sediment basin is located in a Special Protection watershed, no reductions are permitted. In addition, sediment basins located within Special Protection watersheds must meet the requirements listed in items 1 or 2 below (not both). The corresponding

elevation of this volume requirement is the minimum crest elevation of the principal spillway and is also known as the top of dewatering volume.

- ○ A reduction of 50 m^3 (750 ft^3) per total contributing hectare (acre) may be utilized for basins with principal spillways that dewater from the top 150 mm (6 in) only of the water level at any given time within the dewatering zone (i.e. floating skimmer type of outlet structure).
- ○ A reduction of 50 m^3 (750 ft^3) per total contributing hectare (acre) may be utilized for basins with permanent pools greater the 0.5 m (1.5 ft) in depth. Note that the sediment storage volume may be used to achieve this reduction allowance.
- ○ A reduction of 25 m^3 (350 ft^3) per total contributing hectare (acre) may be utilized for basins with length to width ratios of 4:1 or greater. See length to width ratio equations listed below.
- ○ A reduction of 25 m^3 (350 ft^3) per total contributing hectare (acre) may be utilized for basins with dewatering times between 4 and 7 days. See dewatering criteria listed below.

- The total required storage volume is defined as the required sediment storage volume plus the required dewatering volume.

<u>DESIGN EXAMPLE 1</u> – Special Protection watershed (i.e., HQ or EV designation)
Total Drainage Area = 7.28 ha (18 ac)
Disturbed Area = 2.43 ha (6 ac)
Required Sediment Basin Volume: no reductions in dewatering volume are allowed.

Dewatering Volume:	350 m^3/ha x 7.28 ha = 2548 m^3
	(5,000 ft^3/ac x 18 ac) = (90,000 ft^3)
Sediment Storage Volume:	70m^3/ha x 2.43 ha = 170 m^3
	(1,000 ft^3/ac x 6 acres = 6,000 ft^3)
Total Required Storage Volume =	2,718 m^3 (96,000 ft^3)

<u>DESIGN EXAMPLE 2</u> – Non-Special Protection watershed (i.e., TSF, WWF, CWF designations)
Total Drainage Area = 7.28 ha (18 ac)
Disturbed Area = 2.43 ha (6 ac)
0.5 m (1.5 ft) permanent pool provided
4:1 flow length to width ratio provided
4 to 7 day drawn down (dewatering) period provided
Required Sediment Basin Volume: reductions totaling 100 m^3 (1400 ft^3) per total contributing hectare (acre) in dewatering volume from above are allowed.

Dewatering Volume –	250 m^3/ha x 7.28 ha = 1820 m^3
	(3,500 ft^3/ac x 18 acres) = (63,000 ft^3)
Sediment Storage Volume –	70m^3/ha x 2.43 ha = 170 m^3
	(1,000 ft^3/ac x 6 ac = 6,000 ft^3)
Total Required Storage Volume =	1,990 m^3 (69,000 ft^3)

- A minimum of 0.6 m (2.0 ft) of freeboard is required for a sediment basin. The freeboard is measured above the maximum water surface elevation. This elevation will be considered the minimum top of embankment elevation. See outlet design requirements listed below for criteria for the maximum water surface elevation.

Flow Length to Ratio:

- The flow length is to be measured at the elevation of the top of the dewatering zone. The minimum flow length to width ratio is 2:1. Equation 12.5 may be used for computing minimum length in basins that are generally rectangular. For basins that have an irregular shape, the best way to determine average width is to divide the surface area at top of dewatering with the maximum length of the trap at the same elevation. Then the ratio can be verified. Where 2:1 ratio is not possible by grading only, a baffle may be used to increase flow length to the required 2:1 ratio.

(Equation 12.5)

$$L_{(min)} = 1.41(SA)^{0.5}$$

Where: $L_{(min)}$ = Minimum Flow Length – m (ft)
SA = Surface Area at the top of the dewatering volume – m^2 (ft^2)

- When a 4:1 length to width ratio is desired to obtain the reduction allowance listed above (when not located in a Special Protection watershed), Equation 12.6 may be used for computing the flow length in basins that are generally rectangular. For basins that have an irregular shape, the best way to determine average width is to divide the surface area at top of dewatering with the maximum length of the trap at the same elevation. Then the ratio can be verified. Where the 4:1 ratio is not possible by grading only, a baffle may be used to increase flow length to achieve this goal.

(Equation 12.6)

$$L_{(min)} = 2.0(SA)^{0.5}$$

Where: $L_{(min)}$ = Minimum Flow Length – m (ft)
SA = Surface Area at the top of the dewatering volume – m^2 (ft^2)

Outlet Design Requirements (riser type):

- Minimum riser diameter should be 1.25 times outlet pipe diameter. The minimum riser diameter in general is 380 mm (15 in) which corresponds to a minimum outlet pipe diameter of 300 mm (12 in).
- Perforations in the riser structure should be 25 mm (1 in) in diameter. The first row of perforations should be at the sediment storage elevation. A sufficient number of holes should be provided in the riser within the dewatering volume to provide the required 2 to 7-day drawdown time range (4 to 7 days in Special Protection watersheds or if the credit is utilized to reduce the dewatering volume as described above). The holes should be equally distributed around the riser structure in rows that are spaced 300 mm (12 in) vertically. The orifice equation, Equation 12.7 listed below, should be used to determine flows necessary to calculate the dewatering time.

Orifice Flow (HEC-22, *Urban Drainage Design Manual* (FHWA, 2001b)): *(Equation 12.7)*

$$Q_{or} = C_{or}A(2gH)^{0.5}$$

Where: Q_{or} = Flow, m^3/s (cfs)
C_{or} = 0.6 (square-edged uniform orifice entrance conditions)
0.4 (ragged-edged acetylene torched orifices in a corrugated metal pipe riser – HEC-22)
A = Cross sectional area of an orifice, m^2 (ft^2)
g = Acceleration due to gravity, 9.8 m/sec^2 (32.2 ft/sec^2)
H = Depth of water above the center of the orifice, m (ft)

- The dewatering time is defined as the time required to drawdown the basin from the crest of the principal spillway (top of dewatering volume) to cleanout elevation (top of the sediment storage volume). For Special Protection watersheds, it is calculated by multiplying the flow rate times the volume within the dewatering zone. Since the flow rate varies with head, this calculation is performed using a maximum of 300 mm (12 in) steps vertically. The time associated with each step is calculated and then totaled when the final step is at the cleanout elevation. For all other watersheds, the following rule of thumb can be used. Provide 645 mm^2 (1 in^2) of opening per acre of drainage area with all perforations 25 mm (1 in) in diameter and equally spaced vertically along the riser. The lowest row of perforations is at the sediment storage zone elevation (i.e., the cleanout elevation). The number of perforations needed may be determined by dividing the total number of acres tributary to the basin by 0.785.
- When the disturbed drainage area to the sediment basins is composed of highly erodible soils, it is suggested that the dewatering time be pushed out towards the 7-day mark.
- The elevation at which the total storage volume is provided is the minimum elevation for the crest principal spillway (riser structure).

- The riser pipe diameter (or riser structure size) is determined as a function of the head acting on the top of the riser to meet the minimum flow requirement of 0.14 m^3/s (2.0 cfs) per total contributing hectare (acre). The head is calculated as the difference between the water surface elevation and the riser crest elevation.
- Analyze the riser/outlet structure for three possible limiting flow types: weir flow, orifice flow, and pipe flow. The discharge capacity is the smallest of these three flow rates. Discharges through riser perforations may be ignored during this computation.
- The top of a riser structure functions as either a weir or an orifice depending on the stage. Therefore the riser structure must be evaluated using both the appropriate weir flow equation, Equation 12.8 or Equation 12.9, and the orifice flow equation, Equation 12.10.
- The pipe flow equation is listed below. Refer to design requirements listed below for emergency spillway design.
- Provide a minimum of 0.6 m (2.0 ft) freeboard above the maximum designed discharge capacity as defined above. This will be considered the minimum top of embankment elevation. Note, if the emergency spillway is being used to provide part of the 0.14 m^3/s (2.0 cfs) per total contributing hectare (acre) discharge, the freeboard must be provided above the design flow elevation in the emergency spillway.

Weir Flow (sharp crested with no end contractions– used for CMP or other type of pipe riser):

(Equation 12.8)

$$Q_w = C_w L H^{1.5}$$

Where:

- Q_w = Weir flow, m^3/s (cfs)
- C_w = 1.71 in Metric units (3.10 in U.S. Customary units)
- L = Circumference of riser pipe, m (ft)
- H = Depth of flow above the riser crest, m (ft)

Weir Flow (broad crested – used for concrete outlet structure (i.e. Type M inlet top)):

(Equation 12.9)

$$Q_w = C_w L H^{1.5}$$

Where:

- Q_w = Weir flow, m^3/s (cfs)
- C_w = 1.66 in Metric units (3.00 in U.S. Customary units)
- L = Perimeter of inside edges of concrete riser structure, m (ft)
- H = Depth of flow above the riser crest, m (ft)

Orifice Flow:

(Equation 12.10)

$$Q_{or} = C_{or} A (2gH)^{0.5}$$

Where:

- Q_{or} = Orifice flow, m^3/s (cfs)
- C_{or} = 0.6
- A = Cross sectional area of the riser structure, m^2 (ft^2)
- g = Acceleration due to gravity, 9.8 m/sec^2 (32.2 ft/sec^2)
- H = Depth of water above the riser crest, m (ft)

Pipe Flow: *(Equation 12.11)*

$$Q_p = A[2gh/(1 + K_m + K_p L)]^{0.5}$$

Pipe Friction: (*Equation 12.12*)

Metric:
$K_p = 1245792n^2/d_i^{4/3}$

U.S. Customary:
$K_p = 5087n^2/d_i^{4/3}$

Where:
- Q_p = Pipe flow, m^3/s (cfs)
- A = Cross sectional area of the outlet pipe, m^2 (ft^2)
- g = Acceleration due to gravity, 9.81 m/sec^2 (32.2 ft/s^2)
- h = Head above the centerline of the outlet end of the barrel, m (ft)
- K_m = Coefficient of minor losses, can be assumed to be 1.0 for most principal spillway systems
- K_p = Pipe friction coefficient (Equation 12.12)
- n = Manning's coefficient of roughness
- d_i = Inside diameter of the outlet pipe, mm (in)
- L = Outlet pipe length, m (ft)

- A trash rack and an anti-vortex device should be attached to the top of the riser pipe (or structure) to prevent floating debris from blocking the opening in the top of the structure. An anti-vortex device should be used to maintain the design inflow of the riser. Refer to Standard Drawing RC-72M.

Emergency spillway requirements:

- The preferred location of the emergency spillway is in undisturbed ground, if this is not possible and it must be placed in the embankment, provide rock lining or other stable permanent lining which extends to the receiving waterway, channel or other non-erosive outlet.
- The elevation of the emergency spillway crest should be a minimum of 150 mm (6 in) above the top of the dewatering zone (crest of principal spillway).
- If a emergency spillway is not provided (note, this is rare and an emergency spillway should be provided for all sediment basins unless the basin is located within the infield of an exit in which it is surrounded by pavement), the riser structure must be sized to convey the entire minimum flow requirement of 0.14 m^3/s (2.0 cfs) per total contributing hectare (acre). Note that the freeboard is still calculated above this design maximum water surface elevation.
- Provide a minimum of 0.6 m (2.0 ft) freeboard above the maximum designed discharge capacity as defined above. This will be considered the minimum top of embankment elevation. Note: if the emergency spillway is being used to provide part of the 0.14 m^3/s (2.0 cfs) per total contributing hectare (acre) discharge, the freeboard must be provided above the design flow elevation in the emergency spillway.
- Tables provided in HEC-22, *Urban Drainage Design Manual* (FHWA, 2001b), Section 8.4.4.4 or *Hydraulic Design of Spillways* (USACE, 1990) are suggested for determining emergency spillway capacity, however, the Equation 12.14 below is also an acceptable method.

Weir Flow (broad crested): *(Equation 12.13)*

$$Q_w = C_w L H^{1.5}$$

Where:
- Q_w = Weir flow, m^3/s (cfs)
- C_w = 1.55 in Metric units (2.80 in U.S. Customary units)
- L = Bottom width of the spillway at the crest, m (ft)
- H = Depth of flow above the spillway crest, m (ft)

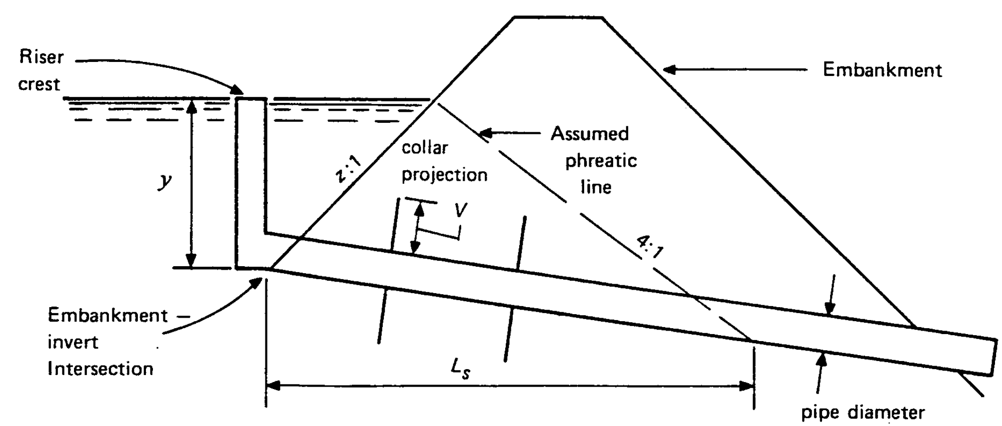
- The maximum spillway side slope is 1V:2H (2H:1V).
- Refer to Standard Drawing RC-71M for details.

Anti-seep collar requirements:

- Anti-seep collars are used when a sediment basin has an outlet pipe associated with the principal outlet structure.

- Anti-seep collars are placed in the embankment of sediment basins to protect the integrity of the structure at the outlet point. At the outlet point of the basin, the water not only exits through the outlet pipe, but also attempts to percolate through the embankment along the exterior surface of the pipe, thus compromising the stability of the berm. Anti-seep collars should be located below the phreatic surface in the embankment and should be spaced evenly along the pipe. Note, bedding gravel should not be placed under the outlet pipe from a sediment basin or permanent stormwater management basin.
- The phreatic surface is defined by a line drawn at a 1H:4V (4V:1H) slope from the top of the dewatering volume on the inside of the sediment basin. This line is used to estimate the embankment saturation zone. Refer to Figure 12.31.

Figure 12.31 Anti-Seep Collar Design



- Determine L_s: The intersection point is the length of the pipe in the saturation zone, L_s by the following procedure. This procedure will provide a 15% increase in the seepage length and is appropriate for the design with permanent stormwater basins.

  NOTE:
  - This procedure needs to be done in U.S. Customary Units and then converted to Metric after the collar size and spacing has been determined.
  - The following chart does provide an increase in the seepage length by 15% verses the one illustrated in the *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000) which only increases the seepage length by 10%. A 10% increase in seepage length is only acceptable for sediment basins that are temporary (the method indicated in the *Erosion and Sediment Pollution Control Program Manual* (PA DEP, 2000) is acceptable for this).

(Equation 12.14)

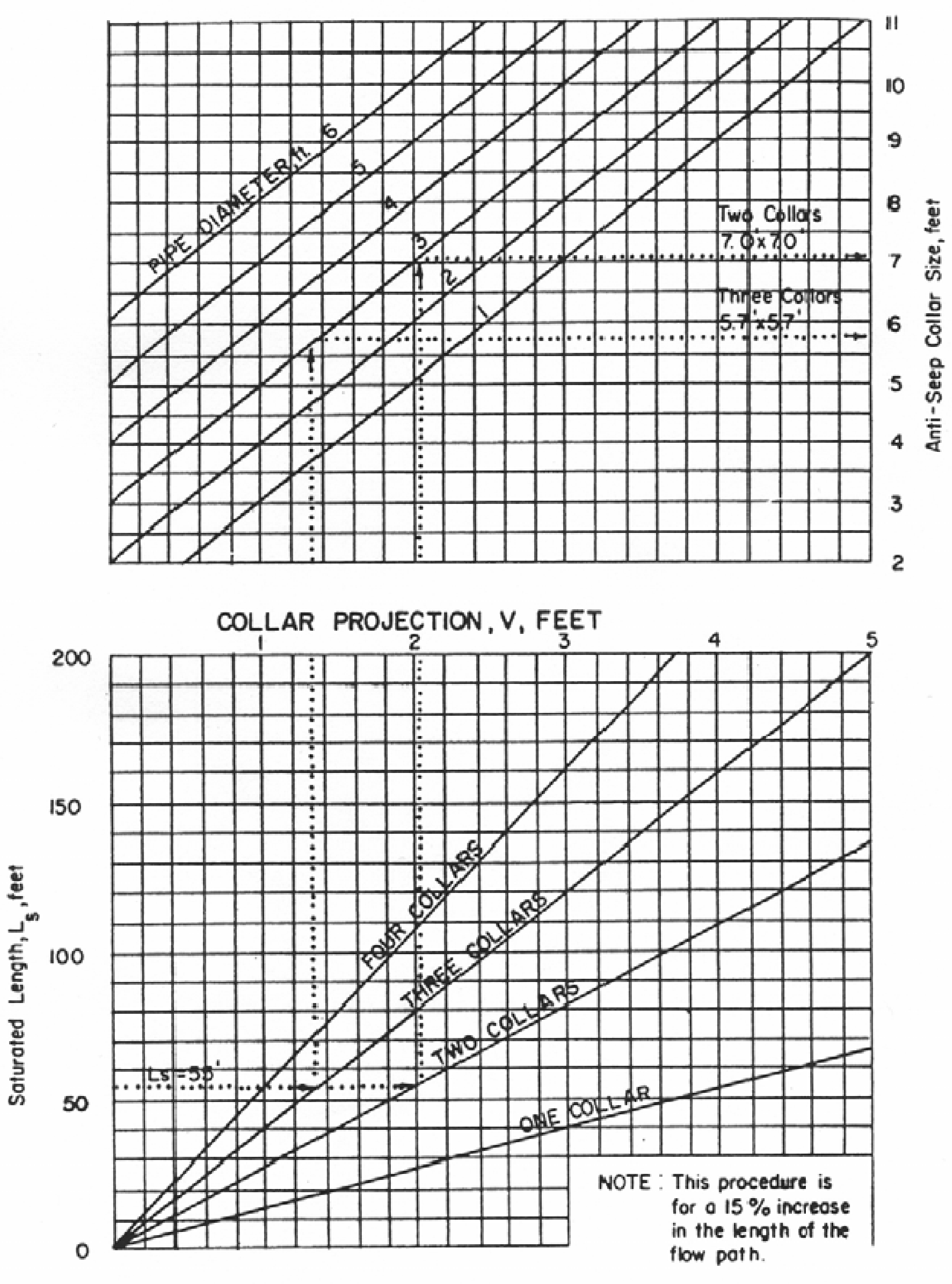
$$L_S = y\,(z + 4)\left[1 + \frac{\text{pipe slope (ft/ft)}}{0.25 - \text{pipe slope}}\right]$$

Where: L_S = Length of pipe in saturated zone, (ft)
y = Vertical distance from upstream invert of principal spillway riser to top of dewatering volume, (ft)
z = Horizontal component of upstream embankment slope, (ft)

Example: y = (8 ft)
inside slope = (2.5H:1V)
embankment pipe slope = (0.1 ft/ft)
L_S = (87 ft)

1. Determine the length of outlet pipe in the saturated zone (L_s) using the Equation 12.14. Refer to Figure 12.31 for variables.
2. Using Figure 12.32, enter L_s value on the left side of the graph.
3. Draw a horizontal line to the point where it intersects with the line that matches the desired number of collars.
4. Draw a vertical line from that point to the line in the upper chart that corresponds to the diameter of the outlet pipe.
5. From that point, draw a horizontal line to the right to read V, the required size of the collar(s).
6. If this diameter does not fit in the embankment, the number of collars should be increased.
7. The maximum spacing between collars should be 14 × V.
8. They should not be located closer than 600 mm (24 in) to a pipe joint.

Figure 12.32 Graphical Determination of Anti-Seep Collar Size



Reference: USDA NRCS.

The following list of other design considerations should also be evaluated:

- The water from the contributing drainage area may enter the sediment basin by any appropriate method. If the runoff is conveyed to the sediment basin by a collector channel or combination of slope pipe and channel, the channel and/or pipe should be sized by the methods indicated in Publication 13M, Design Manual, Part 2, *Highway Design,* Chapter 10.
- Where stormwater runoff from disturbed areas enters a sediment basin from different directions, consider routing flows from the various areas to a single inlet into the sediment basin.
- Adequately sized outlet protection must be provided at end of the outlet pipe from a riser sediment basin.
- The water discharged from a sediment basin must be conveyed to a downstream watercourse by means of an adequately designed channel. When the conveyance channel intersects with the downstream watercourse, appropriate methods should be used to prevent the banks of the receiving water from erosion or scour. An earthen level spreader below a sediment basin is not an acceptable practice.
- Wherever a sediment basin discharges down a long or steep slope, consideration should be given to using a temporary/permanent slope pipe and adequately designed outlet protection.
- During construction a stake should be placed in the center of the sediment basin. This stake is marked with the height corresponding to the top of the sediment storage volume (clean out elevation). Accumulated sediment should be removed from the sediment basin whenever it reaches the marked elevation on the clean-out stake. Removed sediment must be disposed of per appropriate regulatory requirements.
- Bedding gravel should not be placed under the outlet pipe from a sediment basin or permanent stormwater management basin.

Include appropriate references, details and notes from Publication 408, *Specifications* and Publication 72M, *Roadway Construction Standards*. Provide dimensions and elevations to the contractor in a summary table on the plans with the sediment basin details. Inspections of sediment basins should be done on a weekly basis and after each runoff event. If a sediment basin is to be converted to a PCSM BMP (stormwater management basin); refer to the guidance applicable in Chapter 14, *Post-Construction Stormwater Management*.

12.6 IN-CHANNEL E&SPC BMPS

BMPs identified in this section are specifically for use when the construction is to be performed in a channel with flowing water. These BMPs may isolate the work area or divert the flow from the work area.

A. Bypass Channel with Non-Erosive Lining (For Channel Work). A bypass channel can be used as a temporary stream diversion to divert flow in the natural stream channel with a base flow around the work area and back into the natural channel at a downstream location. (See Figure 12.33) If the work area is in a Special Protection or HQ/EV watershed, the type of diversion should be selected on a case by case basis by consulting with the regulatory authority.

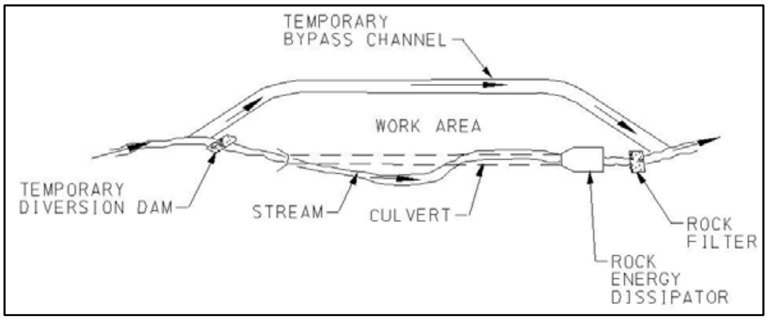
Bypass Channels may be used:

- When the contributing drainage area is any size.
- To divert small streams.
- Where there is a flat flood plain.
- Whenever it is necessary to divert flow for more than 2 days.

When restoring the channel to the natural drainage course, attention must be paid to reconstructing the walls of the channel to ensure the wall integrity. It should be noted that permit requirements should be checked prior to channel restoration.

Bypass channels are to be designed to convey the base flow around the work area for short duration projects or a 1-year storm event for longer duration projects (e.g., box culvert construction). Identify an area upstream for the bypass channel to begin and a downstream area for the flow to be reintroduced to the stream path. Ideal locations would be parallel to the existing stream path.

Figure 12.33 Example Bypass Channel Used For Culvert Installation



Design the channel using the Manning's equation as discussed in Publication 13M, Design Manual, Part 2, *Highway Design*, Chapter 10. In addition, the channel should be lined as suggested in Section 12.5.N.

The location of the bypass channel should allow sufficient room to do the necessary channel work as well as install structures in the vicinities of the tie-ins (e.g., wingwalls). It is also important that the channel not be pushed against a steep slope, especially in erodible soils with low shear strength. Bypass channels should be inspected daily.

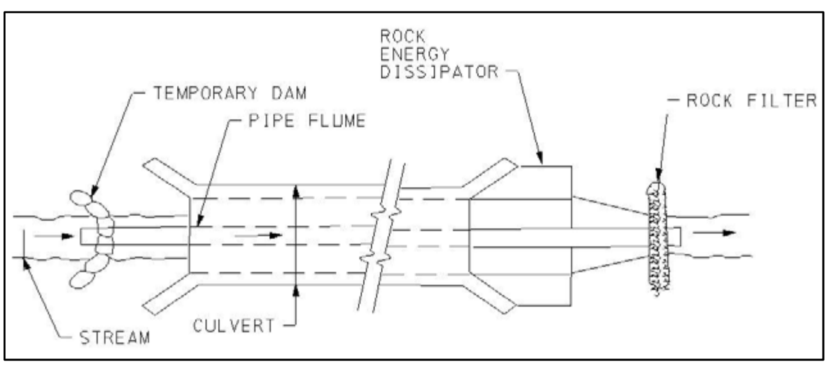
B. Temporary Stream Diversion: Flume through a Work Area. This section describes a method of temporary diversion by use of a flume to convey a stream through the work area. When in-channel work is necessary on the outside edges of a stream, a flume may be constructed to convey water through the work area. If the work area is in a Special Protection or HQ/EV watershed the type of diversion should be selected on a case-by-case basis by consulting with the regulatory authority. Figure 12.34 shows a typical flume through work area diversion.

Flume through a Work Area may be used when:

- The stream width is less than 3 m (10 ft).
- Whenever it is necessary to divert flow for more than 2 days.

Flumes are to be designed to convey the base flow around the work area for short-duration projects or a 1-year storm event for longer duration projects (e.g., box culvert construction). Using the flow calculated, size a culvert to pass the flow using the methods in Publication 13M, Design Manual, Part 2, *Highway Design*, Chapter 10. Refer to *Erosion and Sediment Pollution Control Manual* (PA DEP, 2000) for rock filter design guidance.

Figure 12.34 Flume Through Work Area



Maintenance of flumes should also be considered. The flume should be inspected daily and after each rainfall event. Parts of the flume that may be damaged during a rain event should be immediately replaced.

C. Temporary Stream Diversion: Pump around In-Channel Work Area. Temporary stream diversion using a pump to divert flow from the natural stream channel and discharging it at a downstream location is a method to enable an in channel work area. When in-channel work is necessary, a pump bypass, in combination with cofferdams, can be used to move the base stream flow around the work area. If the work area is in a Special Protection or HQ/EV Watershed, the type of diversion should be selected on a case-by-case basis by consulting with the regulatory authority. Figure 12.35 shows a typical pump around stream diversion.

Pump around diversion may be the least intrusive diversion and should be considered above other methods when the following conditions listed below apply:

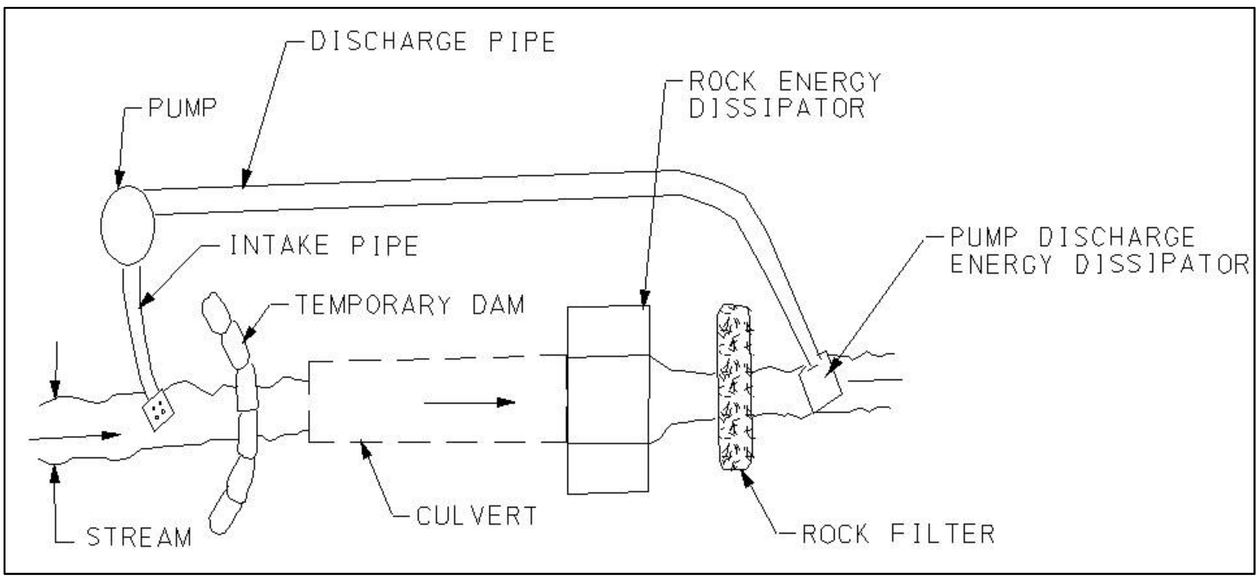
- The stream width is less than 3 m (10 ft).
- The stream will be diverted for less than 2 days.

There is no design method to be considered; however, the work should be done in dry weather. The guidelines below should be followed:

Step 1: Size the pump for base flow.
Step 2: Select a location upstream of the work area to begin the diversion.
Step 3: Select a location downstream of the work area to reintroduce the flow.

Pump-around systems should be monitored throughout the work period.

Figure 12.35 Pump Around In-Channel Work Area



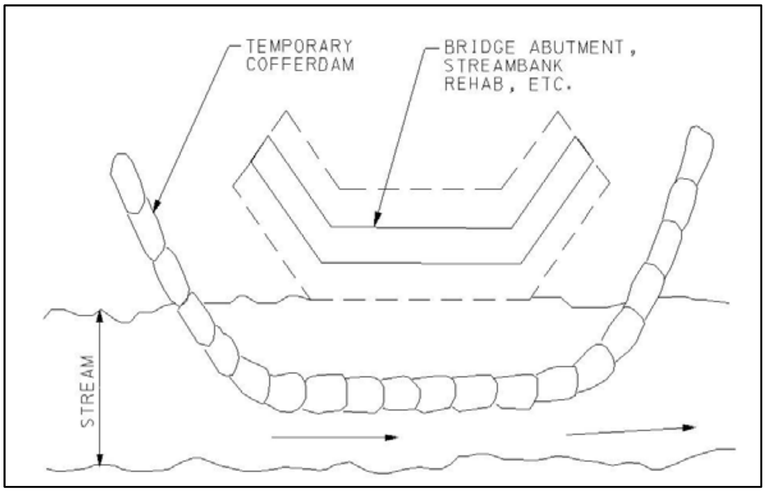
D. In-Stream Cofferdam. An in-stream cofferdam (as shown in Figure 12.36) is a temporary stream diversion device constructed in a channel to keep flow away from an in-channel work area. This will be required when in-channel work is necessary on one side of a stream at a time. If the work area is in a Special Protection or HQ/EV Watershed the type of diversion should be selected on a case-by-case basis by consulting with the regulatory authority.

In-stream temporary diversion device may be used when:

- The stream width is greater than 3.0 m (10 ft).
- The contributing drainage area is greater than 260 ha (640 ac).
- Where concrete barriers are used, normal flow depth should not exceed ½ the height of the barrier.

The work area may contain stagnant water. Evaluate the work area to see if work can be accomplished in an area of dead water or if the areas must be dewatered.

Figure 12.36 In-Stream Temporary Diversion Device



The 2-year design storm should be used to determine the depth of the flow using the methods in Publication 13M, Design Manual, Part 2, *Highway Design,* Chapter 10. The height of the temporary stream diversion device should be no less than 0.2 m (0.6 ft) above the water elevation. Backwater conditions should also be evaluated when considering an in-stream cofferdam diversion. The area blocked off by the temporary stream diversion device should be minimized and it may not exceed 60% of the width of the channel at one time. The temporary stream diversion device should be constructed in low flow conditions.

12.7 GLOSSARY

Abrasion - Removal of stream bank material due to entrained sediment, ice or debris rubbing against the bank.

Act 167 Plan - Stormwater management plans partially funded by PA DEP and prepared by the county for PA DEP-designated watersheds. Act 167 is the Pennsylvania Stormwater Management Act, 32 P.S. §§ 680.1 et seq., which authorizes PA DEP to provide funding for municipal implementation of stormwater programs implementing watershed-based plans conducted by counties.

Angle of Repose - The maximum angle, as measured from the horizontal, at which granular particles can stand.

Aprons - Protective material laid on a stream bed to prevent scour commonly caused by some drainage facility. More specifically, a floor lining of such things as concrete, timber and riprap, to protect a surface from erosion, e.g., the pavement below chutes, spillways, at the toes of dams or at the outlet of culverts. Material placed on the banks is commonly termed a blanket.

Articulating Concrete Block Revetment System - A matrix of individual concrete blocks placed together to form an erosion resistant overlay that meets specific static and hydraulic performance characteristics.

Berm - A narrow shelf or ledge; also a form of dike. A more detailed description might be: 1) the space left between the upper edge of a cut and the toe of an embankment; 2) a horizontal strip or shelf built into an embankment to break the continuity of an otherwise long slope.

Best Management Practice - Activities, facilities, measures, or procedures used to minimize accelerated erosion and sediment to protect, maintain, reclaim and restore the quality of waters and the existing and designated uses of waters within this Commonwealth. (Title 25 PA Code Chapter 102).

Bypass Flow - Flow that bypasses an inlet on grade and is carried in the street or channel to the next inlet downstream.

Channel Lining - The material applied to the bottom and/or sides of a natural or constructed channel. Material may be such things as concrete, sod, grass, rock or any of several other types of commercial linings.

Channel - The term "channel" has been defined numerous ways: 1) the bed and banks that confine the flow of surface water in a natural stream or artificial channel; 2) the course where a stream of water runs or the closed course or conduit through which water runs, e.g., a pipe; 3) an open conduit either naturally or artificially created that periodically or continuously contains moving water or that forms a connecting link between two bodies of water. River, creek, run, branch, anabranch [arroyo, draw, wash] and tributary are some of the terms used to describe natural channels. Natural channels many be single or braided.

Check Dam – A relatively low dam or weir across a channel for the diversion of irrigation flows from a small channel, canal, ditch or lateral. A check dam can also be a low structure, dam or weir, across a channel for such things as the control of water stage or velocity of the control of channel bank erosion and channel bed scour from such things as headcutting.

Concentrated Flow - Flowing water that has been accumulated into a single fairly narrow stream.

Contributing Drainage Area - Total of both disturbed and undisturbed area contributing, usually upslope, runoff to a BMP. Since drainage areas may change during grading operations, roadway construction, installation of sewer lines, and construction of buildings and parking lots, the maximum contributing area is not necessarily the pre- or post-construction drainage area.

Conveyance - A measure of the ability of a stream, channel or conduit to convey water. A comparative measure of the water-carrying capacity of a channel; that portion of the Manning discharge formula that accounts for the physical elements of the channel. Conveyance is expressed as: $(1/n)AR^{2/3}$ where n is Manning's n, A is the cross section area of flow and R is the hydraulic radius. See Manning's Equation.

Countermeasure - A measure intended to prevent, delay or reduce the severity of erosion problems.

County Conservation District - A conservation district, as defined in section 3(c) of the Conservation District Law (3 P.S. § 851(c)), which has the authority under a delegation agreement executed with PA DEP to administer and enforce all or a portion of the erosion and sediment control program in this Commonwealth.

Crest - The maximum elevation of a flood at a specific location. Other definitions are 1) the top of a dam, dike, spillway or weir; 2) the overflow portion of a road or embankment; 3) the summit of a wave; and 4) the peak of a flood.

Detention - The process of temporarily collecting and holding back stormwater for later release to receiving waters.

Dewatering Zone - The zone within a sediment basin where stormwater runoff is held and released in a controlled manner.

Discharge - Volume of water passing a point during a given time. PA DEP defines it in PA Code, Title 25, Chapter 92 as "An addition of any pollutant to surface waters of this Commonwealth from a point source, including: (i) Additions of pollutants from surface runoff and stormwater which is collected or channelized; (ii) Discharges through pipes, sewers or other conveyances which do not lead to a treatment works; (iii) Discharges through pipes, sewers or other conveyances."

Diversion - A facility, including a channel, terrace or dike constructed up-slope of an earth disturbance activity for the purpose of diverting runoff away from an existing or proposed disturbed area.

Drag - The retarding force acting on a body moving through a fluid parallel and opposite to the direction of motion.

Earth Disturbance Activity - A construction or other human activity which disturbs the surface of the land, including, but not limited to, clearing and grubbing, grading, excavations, embankments, land development, agricultural plowing or tilling, timber harvesting activities, road maintenance activities, mineral extraction, and the moving, depositing, stockpiling, or storing of soil, rock or earth materials.

Edge - The revetment limits at top and bottom of slope or bank, and at leading and trailing limits or flanks of the revetment construction.

Embankment - A raised, typically earth, structure used to impound water and/or to carry a roadway.

Emergency Spillway - A rock or vegetated earth waterway around a dam or in a sediment basin (or a permanent stormwater detention facility), built with its crest above the principal spillway. Used to supplement the principal spillway in conveying extreme amounts of runoff safely past the dam to minimize damage and flood hazards.

Erosion - The natural process by which the surface of the land is worn away by water, wind or chemical action.

Erosion and Sediment Pollution Control (E&SPC) - Application of best management practices to stabilize areas disturbed by grading operations, reduce loss of soil due to water or wind action, and prevent water pollution.

Erosion and Sediment Control Plan - A site-specific plan identifying best management practices to minimize accelerated erosion and sedimentation.

Fill Slope - Side or end slope of an earth-fill embankment. Where a fill slope forms the streamward face of a spill through abutment, it is regarded as part of the abutment.

Flow - A stream of water; movement of such things as water, silt and/or sand; discharge; total quantity carried by a stream.

Freeboard - (1) The vertical distance between the level of the water surface, usually corresponding to the design flow and a point of interest such as a bridge beam, levee top or specific location on the roadway grade. (2) The distance between the normal operating level and the top of the sides of an open conduit; the crest of a dam, etc., designed to allow for wave action, floating debris, or any other condition or emergency, without overtopping the structure.

Froude Number - A dimensionless number (expressed as $F = V/(gy)^{1/2}$) that represents the ratio of inertial to gravitational forces; i.e., at a Froude number of unity the flow velocity and wave celerity are equal. High Froude numbers can be indicative of a high velocity associated with supercritical flow and thus the potential or scour and high momentum forces. Stated another way, a number that varies in magnitude inversely with the relative influence of a gravity on the flow patter; $F>1$ indicates rapid (supercritical) flow; $F<1$ indicates tranquil (subcritical) flow.

Gabion - A rectangular basket made of steel wire fabric or mesh that is filled with rock or similar material of suitable size and gradation. Used to construct such things as flow-control structures, bank protection, groins, jetties, permeable dikes and riparian spur dikes. When filled with cobbles, masonry remnants or other rock or suitable size and gradation, the gabion becomes a flexible and permeable block with which the foregoing structures and devices can be built.

Geosynthetic Cellular Confinement System - Honeycomb structure of cells filled with a variety of infill materials that protects and stabilized the underlying strata from the erosive effects of wind and water.

Geotextile - A fabric manufactured from synthetic fiber that is designed to achieve specific engineering objectives, including seepage control, media separation (e.g., between sand and soil), filtration, or the protection of other constructions elements such as geomembranes.

Grade - Three definitions are suggested: 1) the longitudinal slope of a road, channel or natural ground; 2) the finished surface of a canal bed, road bed, top of embankment or bottom of excavation; 3) any surface prepared for the support of such things as conduit paving, ties, or rails.

Hydrodynamic - Involving principles that deal with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them.

Impervious - A surface that cannot be easily penetrated; for instance, rain does not readily penetrate asphalt or concrete surfaces.

Infiltration - The passage of water through the soil surface into the ground.

Inlet - Consider four definitions:1) a surface connection to a closed drain; 2) a structure at the diversion end of a conduit; 3) the upstream end of any structure through which water may flow; 4) an inlet structure for capturing concentrated surface flow. Inlets may be located in such places as along the roadway, a gutter, the highway median or a field.

Longitudinal Profile - The profile of a stream or channel drawn along the length of its centerline. In drawing the profile, elevations of the water surface of the thalweg are plotted against distance as measured from the mouth or from an arbitrary initial point.

Manning Equation - An empirical formula devised by Manning, based upon original work by Ganguillet and Kutter, for computing flow in open channels and pipes. In its present form it has been modified to: $v = (1/n)R^{2/3}S^{1/2}$ where v = velocity, R = hydraulic radius or A/W_p where A = cross section area and W_p = wetted perimeter and S = Hydraulic Gradient. See Manning's n.

Manning's n - A coefficient of roughness used in the Manning Equation for estimating the capacity of a channel to convey water. Generally, "n" values are determined by inspection of the channel.

Mattress - A blanket or revetment of materials interwoven or otherwise lashed together and placed to cover an area subject to erosion.

Municipal Separate Storm Sewer System (MS4) - A separate storm sewer (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels or storm drains) which is all of the following: (i) Owned or operated by a state, city, town, borough, county, district, association or other public body (created by or under State law) having jurisdiction over disposal of sewage, industrial wastes, stormwater or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity, or a designated and approved management agency under section 208 of the Federal Act (33 U.S.C.A. § 1288) that discharges to surface waters of this Commonwealth; (ii) Designed or used for collecting or conveying stormwater; (iii) Not a combined sewer; (iv) Not part of a POTW.

National Pollutant Discharge Elimination System (NPDES) - As authorized by the Section 402 of the Federal Clean Water Act (33 U.S.C.A. 1342), the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Notice Of Intent (NOI) - A complete form submitted for NPDES general permit coverage which contains information required by the terms of the permit and by § 92.81—92.83 (relating to general permits). An NOI is not an application.

Outlet Protection - To armor the outfall of a pipe or culvert in order to reduce stormwater velocity and dissipate the energy of the flow leaving the outlet before it empties into the receiving channel.

Perimeter Controls - BMPs placed or constructed along the perimeter of an earth disturbance area to prevent runoff from entering the disturbed area, or to capture and treat sediment runoff prior to leaving a disturbed area.

Permanent Stabilization - A minimum, uniform 70% perennial vegetative cover and density, or 100% non-vegetative cover which will resist accelerated erosion or the proper placing of other materials to avoid sliding or other movement.

Permissible Velocity - The highest velocity at which water may be carried safely in a canal or other conduit without channel bed scour or bank erosion.

Phase II - The Phase II Final Rule, published in the Federal Register on December 8, 1999, requires NPDES permit coverage for stormwater discharges from certain regulated small municipal separate storm sewer systems (MS4s); and construction activity disturbing between 1 and 5 acres of land (i.e., small construction activities).

Point Source - Any discernible, confined and discrete conveyance, including, but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, CAFO, landfill leachate collection system, or vessel or other floating craft, from which pollutants are or may be discharged.

Principal Spillway - The structure within a sediment basin which controls the discharge of water from the facility.

Project Site - The entire area of activity, development or sale including: (i) The area of an earth disturbance activity; (ii) The area planned for an earth disturbance activity; (iii) Other areas which are not subject to an earth disturbance activity.

Revetment - Erosion resistant materials placed directly on a slope or bank to protect the slope or bank from erosion.

Rills - The formation of numerous, closely spaced streamlets due to uneven detachment of surface soils by runoff on slopes.

Riprap - A layer, facing, or protective mound of broken concrete, sacked concrete, rock, rubble, or stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; also, the stone used for this purpose.

Riser - When the entrance to a culvert may become easily clogged a corrugated metal pipe or a structure made of timber or concrete with small perforations, called a riser, is installed vertically to permit entry of water and prohibit the entry of mud and debris. The riser may be increased in height as the need occurs.

Rolled Erosion Control Products (RECPs) - A temporary degradable or long-term non-degradable material manufactured or fabricated into rolls designed to reduce soil erosion and assist in the growth, establishment and protection of vegetation.

Runoff Event - A rainfall event which produces runoff.

Runoff - That part of the precipitation that runs off the surface of a drainage area after accounting for all abstractions. The portion of precipitation that appears as flow in streams; total volume of flow of a stream during a specified time.

Sag Location - A drop or depression below the surrounding area.

Scour - The displacement and removal of channel bed material due to flowing water; usually considered as being localized as opposed to general bed degradation of headcutting. The result of the erosive action of running water that excavates and carries away material from a channel bed.

Sediment - Soils or other material transported by surface water as a product of erosion.

Sedimentation - The action or process of forming or depositing sediment in waters of this Commonwealth.

Shear Stress - An internal force tangential to the section of which it acts; an action or stress resulting from applied forces that causes or tends to cause two contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact.

Sheet Flow - The flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a stream, it becomes runoff.

Side Slopes - The slope of the sides of a canal, dam, or embankment. Currently sanctioned the naming of the vertical distance first as 1 to 2 (or, frequently, 1:2) meaning a vertical distance of 1m to 2m horizontal. Another form, not as subject to misinterpretation by thoughtless transposition, is 1V on 2H.

Special Protection Watershed, High Quality Watershed or Exceptional Value Watershed - In regards to E&SPC, these are watersheds defined in Pennsylvania under 25 Pa. Code Part 93 and require the water quality of these watersheds to be maintained and protected (generally a higher standard of protection).

Spillway - A passage for spilling surplus water.

Stabilization - The proper placing, grading, constructing, reinforcing, lining, and covering of soil, rock or earth to insure their resistance to erosion, sliding or other movement.

Storm Inlet Protection - Prevents sediment-laden water from entering a storm sewer at new inlets in areas of new development or existing inlets in areas of reconstruction.

Storm Sewer - Principally a drain for conveying stormwater, but at least part of the time a drain that also conveys raw sewage is termed a storm sewer.

Stormwater - Runoff from precipitation, snow melt runoff and surface runoff and drainage.

Stormwater Discharge Associated with Construction Activity - The discharge or potential discharge of stormwater into waters of this Commonwealth from construction activities including clearing and grubbing, grading and excavation activities involving 5 acres (2 hectares) or more of earth disturbance, or an earth disturbance on any portion, part of or during any stage of a larger common plan of development or sale that involves 5 acres (2 hectares) or more of earth disturbance over the life of the project.

Tailwater - Tailwater is the depth of flow in the channel directly downstream of a drainage facility. Often calculated for the discharge flowing in the natural stream without the highway effect (but may include other local effects from development), unless there is a significant amount of temporary storage that will be (or is) caused by the highway facility; in which case, a flood routing analysis may be required. The tailwater is usually used in such things as culvert and storm drain design and is the depth measured from the downstream flow line of the culvert or storm drain to the water surface. May also be the depth of flow in a channel directly downstream of a drainage facility as influenced by the backwater curve from an existing downstream drainage facility.

Temporary Stabilization - Provides immediate control of accelerated erosion from a disturbed area pending further disturbance or stabilization between seeding and establishment of permanent vegetative cover. In this field reference, the principal temporary stabilization measures are mulch, erosion control blankets, and temporary vegetative cover.

Termination - The means of construction at revetment edges e.g. toe trench, bench, etc.

Toe - That portion of a stream cross-section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

Tractive Force -The drag on a stream bank caused bypassing water that tends to pull soil particles along with the stream flow. The force or drag developed at the channel bed by flowing water. For uniform flow, this force is equal to a component of the gravity force acting in a direction parallel to the channel bed on a unit wetted area. Usually expressed in units of stress; i.e., force per unit area.

Transition - A short conduit and/or channel uniting two other conduits and/or channels having different hydraulic elements; a conversion; a variable conduit or channel section connecting one uniform conduit or channel to another of different cross section form.

Waters of the Commonwealth - Rivers, streams, creeks, rivulets, impoundments, ditches, watercourses, storm sewers, lakes, dammed water, wetlands, ponds, springs and other bodies or channels of conveyance of surface and underground water, or parts thereof, whether natural or artificial, within or on the boundaries of this Commonwealth.

12.8 CHAPTER 12 NOMENCLATURE

Symbol	Definition	Units
A	Cross sectional area or surface area	m^2 or ft^2
β	Slope angle	degrees
C_{or}	Orifice coefficient	dimensionless
C_w	Weir coefficient	dimensionless

d	Cell depth	m or ft
d	Stake diameter	m or ft
DA	Drainage area	ha or ac
d_c	Minimum acceptable depth of infill	mm or in
d_i	Inside diameter of outlet pipe	m or in
D_o	Outlet pipe diameter	m or ft (cm or in)
D_{cs}	Cross slope spacing	m or ft
D_{ds}	Downslope spacing	m or ft
FOS	Factor of Safety	dimensionless
γ	Unit weight	kn/m^2 or lb/ft^3
g	Acceleration due to gravity	m/s^2 or ft/s^2
H	Depth of flow above riser crest	m or ft
H_G	Apron depth	m or ft
K_m	Coefficient of minor losses	dimensionless
K_p	Pipe friction coefficient	dimensionless
K_p	Coefficient of passive earth	dimensionless
L	Length	m or ft
L	Stake length	m or ft
L_a	Apron length	m or ft
L_{min}	Minimum flow length	m or ft
L_s	Length of pipe in saturated zone	m or ft
MDS	Maximum Downslope Spacing	m or ft
n	Manning's coefficient of roughness	dimensionless
φ	Minimum angle of repose	degrees
P_p	Required stake resistance of individual stake	N/stake or lb/stake
Q	Discharge, flow	m^3/s or cfs
Q_{or}	Orifice flow	m^3/s or cfs
Q_p	Pipe flow	m^3/s or cfs
Q_w	Weir flow	m^3/s or cfs
R	Radius	m or ft
RSR_a	Required Stake Resistance of stake array	kg/m^2 or lb/ft^2
S	Average slope	percent
SA	Surface area	m^2 or ft^2
SS_u	Ultimate long-term seam strength	kN/m or lb/ft
v	Collar projection	m or ft
V_{cap}	Maximum permissible velocity	m/s or ft/s
W	Width	m or ft
W_a	Apron width	m or ft
W_G	Cover weight	kg/m^2 or lb/ft^2
W_{min}	Minimum filler strip width	m or ft
y	Vertical distance from upstream invert of principal spillway riser to top of dewatering zone	m or ft
z	Horizontal component of upstream embankment slope	m or ft

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